Pine Nutrition Management

Moderator:

H. LEE ALLEN
North Carolina State University

THE EFFECT OF FERTILIZATION ON LUMBER QUALITY IN PLANTATION LOBLOLLY PINE

Mark D. Gibson, Terry R. Clason, and George A. Grozdits[1]

Abstract—The effect of fertilization on lumber grade yield was investigated for six trees selected from a loblolly pine (*Pinus taeda* L.) plantation at the Hill Farm Research Station in Homer, LA. The plantation was originally planted on an 8-foot by 8-foot spacing (680 trees per acre). The stand was thinned from 550 to 100 trees per acre (TPA) 20 years after planting; from 100 to 50 TPA 25 years after planting; and from 50 to 25 TPA 30 years after planting. From age 20 until harvesting at age 30, part of the stand was used for cattle grazing and was fertilized annually with a nitrogen:phosphorous:potassium ratio of 100:35:18 pounds per acre, while part was not fertilized. At age 30, six trees were selected, three from the fertilized portion of the stand and three from the nonfertilized portion. Because the lower boles of all trees were free of branches by age 25, 5 years after fertilization began, it was hypothesized that the fertilized trees would not only have larger diameter growth, but more clear wood, which equates to high-quality lumber grades. Individual tree basal area growth of fertilized trees exceeded that of nonfertilized trees by 40 percent at age 30. All sample trees were sawn into high-quality lumber using a Wood-Mizer$_{TM}$ horizontal bandsaw. Both 1-inch and 2-inch lumber were produced. Nonfertilized (control) trees yielded 63 percent of their volume as lumber. The fertilized trees produced 62 percent of their volume as lumber. Fertilization resulted in a 13-percent increase in high-quality, high-value lumber in the finish grade and a 40-percent increase in high-quality, high-value lumber in the shop grade. Based on cubic foot volume scale, the butt logs consistently gave lower lumber yields than the top logs, which is explained in part by the larger taper of the butt logs.

INTRODUCTION

Under most conditions, thinning and fertilization have increased growth in southern pines. Forest fertilization, in fact, has become a valuable silvicultural tool in our efforts to improve forest productivity. Allen (1987) reported that more than 1.2 million acres of loblolly pine were operationally fertilized by 1987. This acreage increased to 1.5 million by the end of 1988 (NCSFNC 1989). Allen (1987) also indicated that older stands usually respond better to nitrogen or nitrogen plus phosphorus than to phosphorus alone. According to Megraw (1985), fertilization, particularly with nitrogen, increases growth rate in loblolly pine, but in older trees can reduce breast height specific gravity by 5 to 10 percent for several years after treatment. Williams and Farrish (1995) determined that diameter increment increased an average of 24.5 percent over the control treatment during the 2 years following fertilization in 25- and 30-year-old loblolly pine plantations. The volume increment from the fertilizer treatment on a per-tree and per-acre basis showed a similar percentage increase during the same period. Jokela and Stearns-Smith (1993) found fertilization of 14- to 17-year-old loblolly and slash pines (*Pinus elliottii* Engelm. *var elliottii*) still showing cumulative responses for basal area and stand volume growth greater than the controls 8 years after initial treatment.

Growth increase, in terms of additional wood volume, is unquestionably important, but fully as significant is the quality of wood produced by fertilized trees. Quality may be measured in terms of wood properties such as specific gravity, strength, stiffness, rate of growth, etc., or in terms of the quantity and location of defects. Permissible defects for southern pine lumber are specified in grading rules published by the various grading associations. When the tree is converted to lumber, characteristics such as knot size and location, slope of grain, rate of growth, and density, are limiting factors in arriving at a specified grade and reflect the inherent quality of the resource. Since these factors can be influenced by silvicultural practices, forest managers can significantly impact sawn lumber grade yields.

This paper reports the results of a preliminary study to investigate the effects of thinning and fertilization on clear lumber yields from an older loblolly pine plantation.

METHODS

The study was carried out in an established plantation located at the Hill Farm Research Station, Homer, LA. The plantation was originally planted with 1-year-old loblolly pine seedlings on an 8-foot by 8-foot spacing (680 TPA). The entire plantation was thinned from 550 to 100 TPA 20 years after planting; from 100 to 50 TPA 25 years after planting; and from 50 to 25 TPA 30 years after planting. From age 20 until harvesting at age 30, a portion of the plantation was used for cattle grazing and was fertilized annually with a nitrogen:phosphorus:potassium ratio of 100:35:18 pounds per acre, while the remainder was neither fertilized nor grazed. Table 1 shows the mean tree data (d.b.h., height, and basal area) for the plantation at age 20, 25, and at age 30 prior to harvest. At age 30, six trees were selected for harvest, three from the fertilized portion of the stand and three from the nonfertilized portion. The terrain sloped from a hilltop downward toward a pond; hence, to better represent the plantation, one tree from each treatment came from the hilltop, one from midway down the slope, and one from the bottom of the slope. An effort was made to locate sample trees with similar breast height diameters (table 1). After felling, each tree was bucked to produce a single 20.5-foot-long log. These six logs were transported to Wade Correction Center in Homer, LA, for processing into

[1] Professor, Louisiana Forest Products Laboratory, School of Forestry, Louisiana Tech University, Ruston, LA 71272-0045; Professor, Hill Farm Research Station, Louisiana Agricultural Center, Louisiana State University, Homer, LA 71040; and Research Associate, Louisiana Forest Products Laboratory, School of Forestry, Louisiana Tech University, Ruston, LA 71272-0045 (respectively).

Table 1—Mean sample tree data 20, 25, and 30 years after planting

Plantation age	D.b.h.	Height	Basal area
	In.	*Ft*	*Ft^2*
Fertilized			
20	10.6	59	0.613
25	13.5	70	0.994
30	15.8	72	1.362
Control			
20	11.0	62	0.660
25	13.2	71	0.950
30	14.8	74	1.195

lumber. Each log was inspected for straightness and defects. This information was used to buck each log into two separate, shorter logs, thus yielding six logs from the fertilized treatment and six from the control treatment. Ideally, two 10-foot logs plus trim allowance resulted; however, the location of defects and crooks in two of the six original 20.5-foot logs resulted in an 8-foot and 12-foot log from each. Each of these shorter logs was assigned four grading faces and graded based upon the clearness and straightness of each face. All logs were sawn using a Wood-Mizer$_{TM}$ portable horizontal bandsaw by opening the higher grade face first. Both 1-inch and 2- inch lumber were produced. The lumber was graded green, fresh from the saw, using the Southern Pine Inspection Bureau grading rules for shop grade and finish grade lumber (SPIB 1994). Finish grade lumber is used where appearance and finishing qualities are critical and is assigned the grades of B&B, C, C&Btr, and D. Shop grade lumber is produced or selected primarily for industrial uses or remanufacturing purposes and is assigned grades No.1 and No.2.

RESULTS AND DISCUSSION

The lower boles of all trees were free of branches by age 25, 5 years after fertilization began; hence, it was hypothesized that the fertilized trees would not only have larger diameter growth, but more clear wood, which equates to high-quality lumber grades. Results indicate that individual tree basal area growth of fertilized trees exceeded that of nonfertilized trees by 40 percent at age 30 (table 1). Nonfertilized (control) trees yielded 63 percent of their volume as lumber. The fertilized trees produced 62 percent of their volume as lumber. Hence, total lumber yield as a percentage of log volume did not differ significantly among treatments; however, lumber grade (quality) was high for both treatments. Table 2 shows the finish grade lumber yields by treatment. It is evident that the fertilizer treatment produced a larger percentage of high-quality

Table 2—Finish grade lumber yields by treatment and position within the tree

				Grade yield					
Position in tree	No. of logs	Top DIB	Doyle scale	B&B	C	D	Sheathing	Total	Overrun
		In.	*fbm*						
Fertilized:									
Board foot volume									
Tree	6	12.9	316	210	28	88	201	528	67
Butt	3	13.5	201	146	28	37	120	331	65
Top	3	12.2	116	64	0	51	81	197	70
Percent of total volume									
Tree	6	12.9	316	40	5	17	38	100	67
Butt	3	13.5	201	44	8	11	36	100	65
Top	3	12.2	116	33	0	26	41	100	70
Control:									
Board foot volume									
Tree	6	12.9	297	160	32	110	198	500	68
Butt	3	13.2	166	92	14	54	95	254	54
Top	3	12.5	131	68	18	56	103	246	87
Percent of total volume									
Tree	6	12.9	297	32	6	22	40	100	68
Butt	3	13.2	166	36	5	21	37	100	54
Top	3	12.5	131	28	7	23	42	100	87

Table 3—Shop grade lumber yields by treatment and position within the tree

Position in tree	No. of logs	Top DIB	Doyle scale	Grade yield No. 1	No. 2	Sheathing	Total	Overrun
		In.	*fbm*					
Fertilized:								
Board foot volume								
Tree	6	12.9	316	298	96	134	528	67
Butt	3	13.5	201	186	47	98	331	65
Top	3	12.2	116	100	61	36	197	70
Percent of total volume								
Tree	6	12.9	316	56	18	25	100	67
Butt	3	13.5	201	56	14	30	100	65
Top	3	12.2	116	51	31	18	100	70
Control:								
Board foot volume								
Tree	6	12.9	297	267	127	106	500	68
Butt	3	13.2	166	141	64	49	254	54
Top	3	12.5	131	126	63	57	246	87
Percent of total volume								
Tree	6	12.9	297	53	26	21	100	68
Butt	3	13.2	166	55	25	19	100	54
Top	3	12.5	131	51	26	23	100	87

lumber (B&B) than did the control treatment, whether comparing butt logs, top logs, or combining them to obtain an average value for the tree. If the comparison is made with C&Btr (all lumber of grade C and above), the yield for the fertilizer treatment exceeds that of the control for butt logs and the combined tree value, but the control treatment is slightly better in the upper log. This reversal is partly explained by the presence of two 8-foot-long logs in the upper log category, both of which came from the fertilizer treatment. The 8-foot length limits the ability to obtain the higher lumber grades since the minimum allowable lengths are: B&B—8 feet, C—6 feet, and D—4 feet. Hence, what would be a B&B grade in a 10-foot log becomes a C grade in the 8-foot log.

Table 3 shows the shop grade lumber yields by treatment. There is little difference in the yield of No.1 grade between the fertilizer and control treatment.

Table 4 displays the percentage of clear lumber by treatment and grade. The fertilizer and control treatment did differ slightly in the percentage of clear shop grade lumber produced: 11 percent and 8 percent, respectively. This 3-percent difference equates to a 40-percent increase in high-quality, high-value lumber. Finish grade lumber did not differ greatly in the percentage of clear lumber produced by the two treatments: 9 percent for fertilized versus 8 percent for the control. However, this 1-percent difference does equate to a 13-percent increase in high-quality, high-value lumber. This disparity is due in part to the more strenuous grading requirements of the finish grade.

Table 4—Percentage of clear lumber by treatment and grade

Grade	Treatment: Fertilized	Control
	Percent	*Percent*
Finish	9	8
Shop	11	8

Based on cubic foot volume scale, the butt logs consistently gave lower lumber yields than the top logs, which is explained in part by the larger taper of the butt logs.

CONCLUSIONS

Based on this study, the following conclusions can be drawn:

1. Individual tree basal area growth of fertilized trees exceeded that of control (nonfertilized) trees by 40 percent.

2. The percentage of clear lumber produced was slightly greater for the fertilized treatment (9 to 11 percent) than for the control treatment (8 percent).

3. Fertilization produced a 40-percent increase in high-quality, high-value lumber for the shop grade and a 13-percent increase for the finish grade.

4. Based on cubic foot volume scale, the butt logs consistently gave lower lumber yields than the top logs, which is explained in part by the larger taper of the butt logs.

5. Fertilization in conjunction with thinning did increase both volume yield and yield of clear lumber.

LITERATURE CITED

Allen, H.L. 1987. Forest fertilizers: nutrient amendment, and productivity, and environmental impact. Journal of Forestry. 85: 37-46.

Gibson, M.D.; Clason, T.R.; Grozdits, G.A. 1994. Effect of silvipasture management on growth and wood quality of young loblolly pine. In: Abstracts of the eighth biennial southern silvicultural research conference; 1994 November 1-2; Auburn, AL: 48.

Jokela, E.J.; Stearns-Smith, S.C. 1993. Fertilization of established southern pine stands: Effects of single and split nitrogen treatments. Southern Journal of Applied Forestry. 17(3): 135-138.

Megraw, R.A. 1985. Wood quality factors in loblolly pine. Atlanta: Tappi Press. 88 p.

NCSFNC. 1989. Eighteenth annual report. Raleigh, NC: North Carolina State Forest Nutrition Cooperative, College of Forest Resources, North Carolina State University. 38 p.

SPIB. 1994. Southern Pine Inspection Bureau grading rules. Pensacola, FL: SPIB. 225 p.

Williams, R.A.; Farrish, K.W. 1995. Effects of fertilization and herbicide application on the growth and yield of older loblolly pine plantations—two year results. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 633 p.

NITRATE DISTRIBUTION IN SOIL MOISTURE AND GROUNDWATER WITH INTENSIVE PLANTATION MANAGEMENT ON ABANDONED AGRICULTURAL LAND

Thomas M. Williams[1]

Abstract—Loblolly pine (*Pinus taeda* L.) and sweet gum (*Liquidambar styraciflua* L.) were grown with irrigation, continuous fertilization, and insect pest control on a 1-year-old abandoned peanut (*Arachis hypogaea* L.) field. Wells and tension lysimeters were used to measure nitrate in soil moisture and groundwater on three replicate transects for 2 years. Each replication had five treatments: maximum plantation management, complete vegetation control, optimal irrigation, optimal fertilization, and insect pest control; minimum plantation management, complete vegetation control; old field, no activity; forest edge, 50-year-old longleaf pine forest; lake edge, pine-to-hardwood transition. Groundwater nitrate concentration beneath the minimum treatment [8.1 milligrams per liter (mg/)] was significantly higher than the maximum treatment and the old field (5.84 and 5.05 mg/l, respectively). All three treatments frequently exceeded the 10 mg/l drinking water standard. The forest and lake edge were both significantly lower at 0.30 and 0.32 mg/l respectively. Averaged over all depths, soil moisture nitrate concentrations in the two plantation treatments were significantly higher (11.4 and 11.5 mg/l) than the old field (5.4 mg/l), which was significantly higher than the forest edge (0.24 mg/l).

INTRODUCTION

Abandoned agricultural land is being actively examined for highly intensive forest management in the Southeastern United States. In addition to DOE and USDA interest in bioenergy production, forest industry is also examining intensive management for fiber production. Industry is experiencing an increased demand for fiber on company lands coupled with increasing limitations on forest land use. Concerns for wetlands protection, biodiversity, and forest practice certification will tend to limit the extent of commercial forest land dedicated to intensive management. Several companies are investigating use of highly intensive management on abandoned agricultural lands as a source of increased fiber production.

It is usually assumed that intensive forestry on agricultural land will produce few environmental concerns, since the proposed management is no more intense than current agricultural practice. Although nitrate leaching can be a problem in agriculture (Leslie and Barnett 1991), it is seldom a problem in normal southern forest management (Riekerk and others 1989). Plant uptake and heterotrophic bacteria are believed to compete more effectively than nitrifiers for available NH4+ in forest soils (Vitousek and others 1982). However, there is some evidence that nitrifiers can also be effective competitors, at least in grassland systems (Davidson and others 1990). Johnson and Todd (1988) found that quarterly nitrogen (N) fertilization resulted in greater nitrate loss than a single annual application. Johnson(1992) states nitrifying bacteria may be more effective competitors on better sites and that frequent fertilization might also increase their importance on “N poor” sites, more common on forest land. Use of herbicides for vegetation control seldom results in leaching of herbicide (Neary 1983), but herbicide application to forest land may result in increased nitrate leaching (Neary and others 1986). Finally, growth rates, and thereby N uptake, of most agricultural crops greatly exceed tree growth rates early in a forest rotation. It appears that application of intensive forest management to abandoned agricultural land might increase nitrate leaching early in plantation management.

Site Description

This paper outlines nitrate leaching results for the first 2 years of intensive plantation management on an abandoned peanut field on the lower coastal plain of southwest Georgia. The study was done at International Paper’s Silver Lake Experimental Forest near Bainbridge, GA, on a former peanut field near the shore of Silver Lake. Silver Lake is a small stream valley that flooded subsequent to creation of Lake Seminole by a dam on the nearby Flint River. Soils of the site are Lakeland (Typic Quartzipsamments) and Eunola (Aquic Hapludult). In the old field, soils are excessively well-drained fine sand to loamy sand.

The plantation management experiment is laid out as three replicates of a randomized block, 2x4 factorial experiment. Factors are species (loblolly and sweetgum) and management intensity (control, irrigation, irrigation + fertilizer, and irrigation + fertilizer + pest control). Since all the blocks had herbaceous competition control and genetically improved seedlings, the controls were still rather intensive cultural treatments.

METHODS

The nitrate study addressed two main environmental concerns: (1) Do the cultural treatments result in leaching of nitrate? (2) Was there groundwater transport of nitrate to the adjacent Silver Lake? Both these questions were examined using multilevel soil moisture and groundwater sampling of three transects, one from each replicate. Each transect consisted of five plots: minimum treatment (control defined above), maximum treatment, old field outside of the treatment plots, within a 50-year-old pine stand surrounding the field, and at the edge of the lake. In each replicate, the five plots were aligned perpendicular to the land slope from the field to the lake edge (fig. 1).

[1] Professor of Forest Resources, Baurch Forest Science Institute, Department of Forest Resources, Clemson University, Box 596, Georgetown, SC 29442.

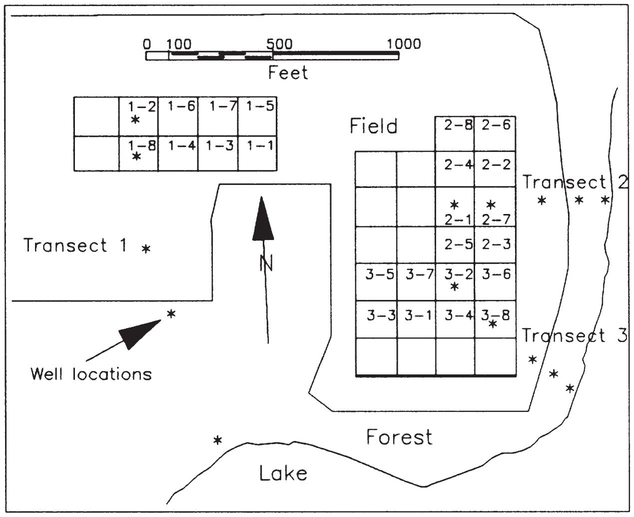

Figure 1—Map of study area. Plot numbers (1-1) represent replication-treatment. Odd treatment numbers are loblolly plots, even are sweetgum. Minimum treatment = 1&2, Irrigation = 3&4, Irrigation+Fertilizer = 5&6, Maximum = 7&8.

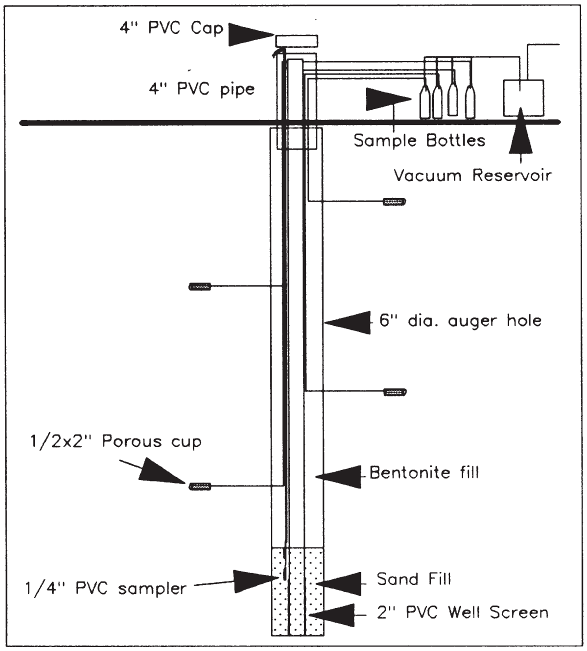

Figure 2—Schematic of water sampling devices placed at each well location.

In April 1995, a 15-centimeter (cm) diameter hole was augured below the water table and a 5-cm PVC well screen was placed 60 to 120 cm below the water table at each sample location. All plots, except the lake edge, had water tables at approximately 6 meters (m) depth and auger holes were 7 to 7.5 m deep. Soil samples were taken in 15-cm intervals throughout the depth of each installation. Soil colors were consistent with the water tables discovered in April. No soil, and few mottles, showed low chroma indicative of poor soil aeration. In addition to the well screen, small screened samplers (5 cm by 6 millimeters (mm) diameter) were also installed near the water table in several wells. The purpose of these was to collect small volume samples without disturbance associated with bailing of the well screen. Horizontal drilling was used to place four (2.5 cm by 10 cm long) tension lysimeters in undisturbed soil approximately 30 cm from the central shaft. Tension lysimeters were connected to sample bottles in a box on the soil surface, and all sample bottles were connected to a central vacuum manifold (fig. 2).

Trees were planted in February 1995 and cultural treatments were begun in April 1995. Sampling of soil moisture and groundwater was begun in May 1995 and samples were collected twice each month until December 1996.

Tension lysimeters were maintained at tensions between 0.5 and 0.7 bar continuously throughout the period. At each sampling, water was poured from the lysimeter sample bottles into 60-milliliters (ml) polyethylene bottles, all 5-cm wells were pumped until clear and a 60-ml sample was collected, and a 60-ml sample was collected from any of the small screened samplers that were below the water table. All samples were placed in coolers and returned to the Baruch Institute Lab in Georgetown, SC, and nitrate determinations were made within 24 hours. Nitrate analyses were done using cadmium reduction technique on a Technicon autoanalyser (Greenberg and others 1992).

Water tables were measured in each 5-cm well prior to each sampling. A local datum was established on a dock in Silver Lake and given an arbitrary elevation of 30.5 m (100 foot). Elevation of each well top was surveyed from the local datum by closed traverse. Lake level was measured by a tape at each sampling. Water levels in the wells were measured with two connector wires and a heavy weight. The wire was connected to a simple amplifier circuit that sounded a speaker when water completed the circuit. The wire, marked at 30-cm intervals, was lowered into the well until the speaker sounded. The distance was then measured with a tape to the nearest marker. All well depths were converted to elevation relative to the temporary datum.

RESULTS

Nitrate Concentrations in Soil Moisture

The tension lysimeters were connected to the vacuum system constantly such that water was withdrawn from the soil whenever soil moisture potential was below 0.5 bar. All percolating water was collected during the 2-week period between samplings. However, the use of tension of 0.5 to 0.7 bar also included some water that was not free to percolate.

Nitrate concentrations in the individual lysimeters were highly variable over the 2 years of sampling with ranges over four orders of magnitude (0.01 to >100 mg/l) and coefficients of variation of over 100 percent. Average values (fig. 3) showed considerable variation among depths, replications, and treatments. There were no significant differences between depths but significant differences in treatments, replications, and all two-way interactions.

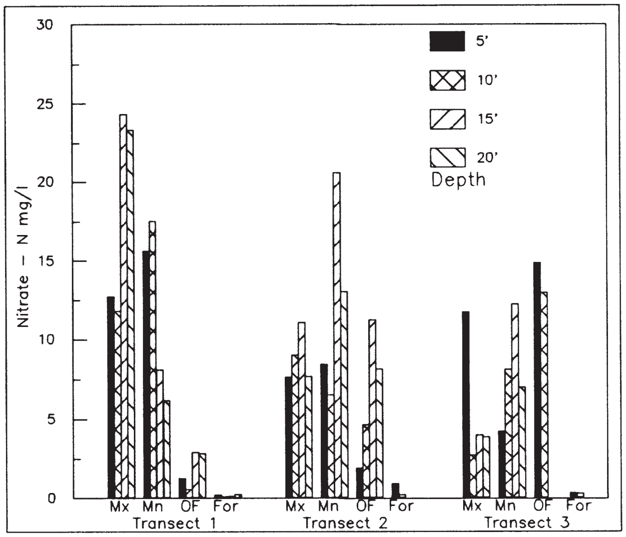

Figure 3—Soil moisture nitrate-nitrogen concentrations averaged by depth, transect, and treatment. MX-Maximum, Mn- Minimum, OF-Old Field, For-Forest.

There is a clear separation between treatments in the field compared to those in the natural forest. Comparison of treatments, averaged over all depths and reps, indicates soil moisture nitrate concentrations are significantly higher on both the plantation treatments than on the other three treatments (fig. 4). The old field vegetation is also significantly higher than the two natural forest treatments. There is little difference in the ranking whether the first year's or both years' data are included in the analysis.

Nitrate Concentrations in Groundwater

Groundwater nitrate concentrations were similar to soil moisture in relatively high variability, individual well coefficients of variation over 100 percent, and mean values. Groundwater nitrate, however, is evaluated in relation to drinking water standards. Compliance with drinking water standards requires the range of measured concentrations be below 10 mg/l. The only well on the abandoned field that complied with the standard was the maximum treatment plot on transect 2 (fig. 5).

The pattern of groundwater nitrate concentrations by treatment was nearly identical to that of soil moisture. The only difference was the maximum treatment was not significantly different from the field treatment for groundwater. In 1995 the minimum and maximum plots were similar and not significantly different. With both years combined, the nitrate concentration below the minimum treatment was significantly higher than the maximum (fig. 6).

The second objective was also to determine the potential of nitrate movement into Silver Lake by groundwater flow. Nitrate concentrations were clearly higher below the

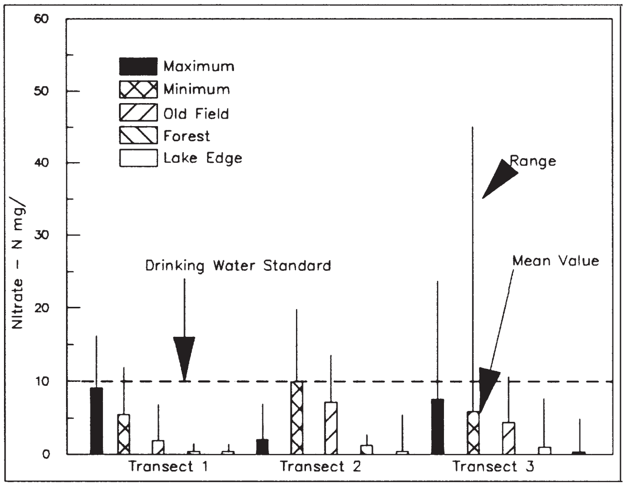

Figure 5—Groundwater nitrate-nitrogen concentration means and ranges compared to drinking water standards.

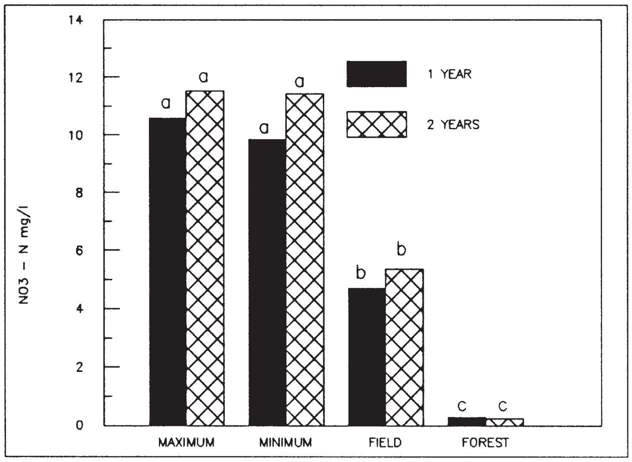

Figure 4—Average soil moisture nitrate-nitrogen concentrations over all depths and transects for 1995 and both years combined. Bars with the same letter within a year are not significantly different at 95 percent confidence level.

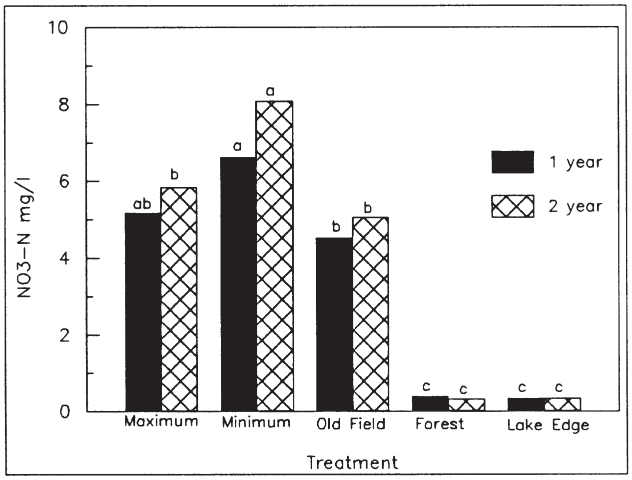

Figure 6—Groundwater nitrate-nitrogen concentrations for 1995 and both years combined. Bars with the same letter within a year are not significantly different at 95 percent confidence level.

abandoned peanut field. However, contamination of the lake requires groundwater flow toward the lake. In no case was there potential for flow from the field to the lake. The water table in the forest near the lake edge was consistently higher than any of the wells in the field (fig. 7).

DISCUSSION

In this study, nitrate concentrations in soil moisture and groundwater were significantly elevated in an abandoned peanut field for at least 2 years after agriculture ceased. Groundwater nitrate concentrations beneath all plots on the abandoned field violated drinking water standards with the minimum plantation management having the highest concentrations. Intensive plantation management increased the nitrate concentration in soil moisture above that found in the abandoned field with no treatment. There was no difference between the minimum and the maximum treatments in soil moisture nitrate.

The most important factor in nitrate concentrations was the presence of an abandoned peanut field. Values under the field were more than an order of magnitude larger than in the old forest or lake edge. Groundwater nitrate often exceeded drinking water standards in nearly every well beneath the field and never exceeded the standards outside of the field. Nitrogen fixation is active in peanuts, even in the dark and after aboveground parts are removed (Siddique and Bal 1991). Lynd and Ansman (1991) found decomposing nodules of sirato (*Macroptilium atropurpureum* DC.) stimulated rapid nitrification. Peanut residue also increased the rate of nitrogen mineralization (Smith and Sharpley 1990) in contrast to nonleguminous residue that caused immobilization of soil nitrogen. It seems quite likely that nitrification was enhanced throughout the abandoned peanut field, resulting in high nitrate concentrations in both soil moisture and groundwater.

Nitrate concentrations were also significantly higher beneath the plantation treatments than the old field.

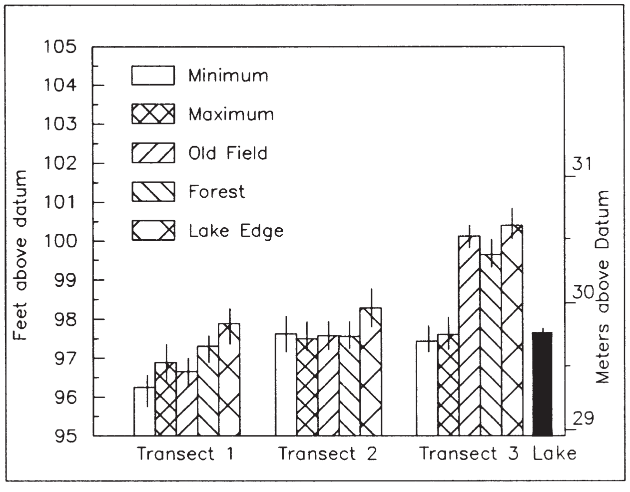

Figure 7—Average water table elevations and 95 percent confidence limits, relative to an assumed datum (30.5 meters).

Plantation establishment seems to have increased nitrate concentrations, although there was little difference between the minimum and maximum treatments. Nitrification has been found associated with vegetation control using herbicides (Likens and others 1969, Neary and others 1986, Munson and others 1993). These studies suggest that elimination of competing vegetation may result in increased nitrate leaching. All plantation treatments in this study included nearly complete elimination of competing vegetation.

In this study, intensive plantation management on an abandoned peanut field showed nitrate concentrations in soil moisture and groundwater at undesirable levels. It suggests caution in application of intensive plantation culture on abandoned agricultural land. It is not possible to determine causes or predict results from a single study, especially one established on the site of a crop that exhibits vigorous nitrogen fixation. However, agricultural land does have conditions more favorable to nitrification (better drainage, higher pH) than forested lands.

ACKNOWLEDGMENT

I would like to thank James Morris and Louwanda Jolley for dedicated service in sample collection and analysis. International Paper provided lodging at Silver Lake during sampling and the study was funded by Cooperative Agreement 18-409 from the USDA Forest Service, Southern Research Station.

LITERATURE CITED

Davidson, E A.; Stark, J.M.; Firestone, M.K. 1990. Microbial production and consumption of nitrate in an annual grassland. Ecology. 71: 1968-1975.

Greenberg, A.E.; Clesceri, L.S.; Eaton, A.D. 1992. Standard methods for the examination of water and wastewater, 18th ed. Washington, DC: American Public Health Association.

Johnson, D.W. 1992. Nitrogen retention in forest soils. Journal of Environment Quality. 21: 1-12.

Johnson, D.W.; Todd, D.E. 1988. Nitrogen fertilization of young yellow poplar and loblolly pine plantations at different frequencies. Soil Science Society of America Journal. 52: 1468-1477.

Leslie, A.R.; Barrett, M. 1991. Health advisories and alternative agricultural practices: regulatory basis for concern and its influence on regulation. ACS Symposium Series 465. American Chemical Society: 16-26.

Likens, G.E.; Bormann, F.H.; Johnson, N.M. 1969. Nitrification: importance to nutrient losses from a cutover forested ecosystem. Science. 163: 1205-1206.

Lynd, J.Q.; Ansman, T.R. 1991. Soil nitrification indeed nitrosylleghemoglobin with repressed nitrogenase activity during regrowth of forage sirato(*Macroptilium atropurpureum* DC.). Journal of Plant Nutrition. 14: 219-234.

Munson, A.D.; Margolis, H.A.; Brand, D.G. 1993. Intensive silviculture treatment: Impacts on soil fertility and planted conifer response. Soil Science Society of America Journal. 57: 246-255.

Neary, D.G. 1983. Monitoring herbicide residues in springflow after an aerial application of hexazinone. Southern Journal of Applied Forestry. 7: 217-223.

Neary, D.G.; Bush, P.B.; Douglass, J.E. 1986. Water quality in ephemeral streams after site preparation with the herbicide hexazinone. Forest Ecology and Management. 14: 23-40.

Riekerk, H.; Neary, D.G.; Swank, W.T. 1989. The magnitude of upland silvicultural non-point source pollution in the South. In: Hook, D.D.; Lea, R., eds. Proceedings of the symposium: The forested wetlands of the southern United States. Gen. Tech. Rep. SE-50.Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 8-18.

Siddique, A.M.; Bal, A.K. 1991. Nitrogen fixation in peanut nodules during dark periods and detopped conditions with special reference to lipid bodies. Plant Physiology. 95: 896-899.

Smith, S.J.; Sharpely, A.N. 1990. Soil nitrogen mineralization in the presence of surface and incorporated crop residues. Agron. Journal. 82: 112-116.

Vitousek, P.; Gosz, J.R.; Grier, C.C. [and others]. 1982. A comparative analysis of nitrification and nitrate mobility in forest ecosystems. Ecol. Monog. 52: 155-177.

EFFECTS OF SOIL COMPACTION AND ORGANIC MATTER REMOVAL ON MORPHOLOGY OF SECONDARY ROOTS OF LOBLOLLY PINE

Charles H. Walkinshaw and Allan E. Tiarks[1]

Abstract—Root studies are being used to monitor possible changes in growth of loblolly pines on a long-term soil productivity study site. Here, we report the results of a preliminary look at roots in the sixth growing season. Roots were collected from loblolly pines grown in soil that was first subjected to three levels of compaction (none, moderate, severe) and three levels of organic matter removal (stem only, total tree, and total aboveground biomass). Roots were fixed, sectioned, and stained for examination by light microscope. The proportion of roots with bark formation decreased from 70 percent in uncompacted soil to 43 percent in severely compacted soil. Depletion of starch grains was significantly less in samples from uncompacted soil than in compacted soil.

INTRODUCTION

Management practices that change soil properties may affect growth and health of secondary roots and eventually the long-term productivity of the site. The USDA Forest Service's long-term soil productivity (LTSP) study, which has recently been installed at several sites in the United States and Canada (Tiarks and others 1993) is designed to measure such changes over a rotation. Its primary purpose is to monitor changes in productivity and soil processes. Three levels of soil compaction, three levels of organic matter removal, and two levels of vegetation control were applied (Powers and others 1990). Ultimately, interpretation of the relationship between these treatments and productivity will require the linking of changes in soil properties to soil processes, including root growth and health.

Anatomical study of roots is particularly useful for assessing root health (Walkinshaw 1995). Soil compaction affects root health and subsequent crop production in annual crops (Allmaras and others 1988, Feldman 1984). Compacted soils have fewer and smaller pores, and such conditions damage roots and alter their morphology. Loblolly pine roots less than about 5 millimeter (mm) in diameter appear to be particularly vulnerable to soil compaction (Copeland 1952). Shedding of dead cortex reduces root diameter and eliminates large numbers of root hairs in loblolly and other conifers (Kozlowski and Scholtes 1948, Leshem 1974). Many injuries develop after the period of root extension during secondary root development (Coutts 1987).

The objectives of the present study were to evaluate the usefulness of root morphology variables as indicators of root health, and to measure the effects of soil compaction and organic residue removal on anatomy of secondary roots.

METHODS

The root samples used were collected at the LTSP site located in Rapides Parish, LA, (Tiarks and others 1991) at the beginning and end of the sixth growing season. A 40-year-old loblolly pine stand on the site was harvested in 1989. The compaction treatments (none, moderate, and severe) and organic matter treatments (stem only, total tree, and total aboveground biomass) were applied soon after harvest. The plots were planted with containerized seedlings from 10 open-pollinated loblolly pine families in February 1990. Soil bulk densities were measured with a core sampler at planting and at stand age 5. Tree volumes were calculated on the basis of pine heights and diameter at breast height (d.b.h.) measured at age 6 (Schmitt and Bower 1970).

Roots were sampled twice in the sixth growing season. In the first sampling (March 24, 1995) roots from 10 trees were collected in the plots representing the extremes of the treatments (OM_0C_0 and OM_2C_2). In the second sampling (October 10, 1995) we sampled roots of five pines per treatment. There were 9 different treatments, and an average of 14 roots per tree was collected at each sampling. The March sampling yielded 264 root specimens and the October sampling 753. Root samples were from pines randomly selected from among the families. To ensure that nonpine roots were not included in the samples, we collected only in subplots that had received herbicide treatment.

Roots were collected in a 25-centimeter (cm) by 25-cm area located about 1 meter (m) from the stem of a pine. All soil and roots between a depth of 2 cm and a depth of 20 cm were collected and the roots gently shaken to remove excess soil. The center 2 to 4 cm of each root was excised and placed into formalin-acetic acid-alcohol (FAA) fixative for 14 days (Sass 1951). Fixed root specimens were re-cut to 1 to 3 mm, dehydrated in alcohol series, embedded in paraffin, and cut into 7 micrometers (m) to 10 m transverse sections. Sections were stained by hematoxylin-eosin, Papanicolaou's schedule, or the acid-schiff procedure (Haas 1980). Three to nine stained sections were prepared from each root, but only the first usable section from each root was read. Observations on root sections were at 100 to 500 diameters with a photomicroscope. Halogen and polarized light sources and neutral density filters were used

[1] Plant Pathologist and Soil Scientist, respectively, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360.

to differentiate tannin and cellulose:lignin complexes. The percentage of roots meeting the criteria for a variable was calculated by tree. If the cambium appeared dead and tannin accumulation was excessive, the root was considered to be dead and not used in further analysis. No dead roots were found in the March sampling and only four roots were dead in the October sampling.

Variables for Histological Observations

Based on past observations of root samples from Louisiana (2,619 roots), Mississippi (623 roots), and North Carolina (1,221 roots), 10 variables were selected for further testing. They were:

Variable	**Description**
Cortex shedding	Cortical cells are dead and remain attached or are released into the soil. The shed is invaded by many soil microbes.
Periderm formation	The first stage in replacement of shed cortex. Cortical cells are coated with a protective layer of tannin and cellulose:lignin complex.
Bark formation	Intact layer of bark cells identical to those found in the stem encompasses the root. Protects the root from injuries and microbial invasion.
Starch	Degradation of starch grains in the cells is degradation 50 percent in the cells. Starch test in cortical and ray cells is negative.
Tannin	Accumulation of tannin-containing cells in accumulation the cortex, rays, and inner xylem. Number of cells with accumulations range from less than 10 to over 100.
Mycorrhizal	Status of short roots that are shed during status the early stage of cortical-cell death. New lateral roots often develop at the sites where mycorrhizal roots have shed.
Lateral root	Formation of roots that arise from the xylem formation and phloem and remain permanent rather than being shed like root hairs and mycorrhizae.
Pathogenic	Infection of living cambial or fiber cells, infection in contrast to invasion of the dead cortex in the shed. Root appears to die from this invasion.
Section	Tissue tearing that occurs during sectioning tearing and makes it difficult to examine specimens for periderm formation, starch degradation, and formation of lateral roots.
Number of	Number of starch-containing plastids per cell starch grains when the cell is viewed at a single focal per cell length at 100 to 500 diameters.

Data Analysis

Treatments were not replicated, but the plots were sufficiently large and uniform so that within-plot sampling could be considered replication in this preliminary test of root variables. Thus, trees within plots were used as replications. Analysis of variance was used to separate the means of the two treatments sampled in March. For the October sampling, analysis of variance for a factorial design was used to test the significance of the main effects (compaction and organic matter level) and of their interaction.

Results and Discussion

March sampling—Four of the 10 variables measured on samples collected March 24, 1995, were significantly affected by the two soil treatments (table 1). The combination of soil compaction and removal of aboveground organic matter delayed cortex shedding, periderm formation, and starch degradation. The proportion of roots with complete bark was 70 percent in the severely treated plot and only 43 percent in the low-impact

Table 1—Measurements of root samples collected March 24, 1995 by soil treatments

	Compaction-OM treatment		
Root variable	None-stem removal only	Severe-total aboveground	Probability of> F value
	Percentage of roots		
Cortex shedding	52	31	0.012
Periderm formation	53	28	0.002
Bark formation	43	70	0.001
Starch degradation	29	6	0.001
Tannin accumulation	12	12	0.830
Mycorrhizal status	9	8	0.851
Lateral root formation	6	5	0.809
Section tearing	28	18	0.166
Pathogenic infection	0	0	1.000
	Grains per cell		
Starch formation	10.9	10.7	0.848

treatment. The other variables were not significantly affected by the soil treatments.

October sampling—Of the 10 variables measured in the fall sampling, only 4 were significantly affected by the treatments (table 2). Cortex shedding, periderm formation, section tearing, and number of starch grains per cell were affected by soil compaction, while only periderm formation and number of starch grains per cell were significantly affected by removal of organic matter. None of the interaction terms was significant.

Removal of limbs and foliage during the harvest decreased the proportion of roots with periderm formation from 35 to 24 percent (table 3). Removal of the forest floor had no further effect on the percentage of roots with periderm formation. Removal of organic matter had a mixed effect on the number of starch grains per root cell, with the greatest number of starch grains per cell occurring in samples from the intermediate treatment. Although this effect was statistically significant, a biological explanation is not readily apparent.

As compaction increased, the percentage of roots with periderm formation decreased (table 3), with the greatest effect occurring as compaction was increased from 1.40 to 1.46 grams per cubic centimeter. The number of starch grains per root cell increased as the level of compaction increased. The change in number of starch grains per cell was proportional to the change in bulk density. The percentage of roots with cortex shedding decreased as

Table 2—Probability of differences occurring by chance for root variables in samples collected October 10, 1995

Root variable	Compaction	Organic matter treatment	Interaction
	---------- Probability ----------		
Cortex shedding	0.017	0.164	0.060
Periderm formation	0.016	0.045	0.171
Bark formation	0.084	0.126	0.299
Starch degradation	1.00[a]	1.00	1.00
Tannin accumulation	0.362	0.466	0.132
Mycorrhizal status	0.357	0.145	0.300
Lateral root formation	0.556	0.128	0.168
Section tearing	0.030	0.577	0.978
Pathogenic infection	0.289	0.537	0.586
Starch grains	0.001	0.025	0.089

[a] Only four roots showed signs of starch degradation.

Table 3—Means (percentage) of roots with periderm forming and number of starch grains per root cell, by soil treatment, for sample collected October 10, 1995

	Organic matter removed			
Compaction	Stem only	Total tree	Total above ground	Mean
	Pct. of roots with periderm forming			
None (1.40a)	45	27	33	65
Moderate (1.46)	28	27	31	27
Severe (1.49)	33	20	9	21
Mean	35	24	25	
	Number of starch grains per cell			
None (1.40)	5.0	6.7	6.1	5.9
Moderate (1.46)	7.0	6.9	6.4	6.7
Severe (1.49)	6.8	7.5	7.1	7.1
Mean	6.3	7.0	6.5	

a = bulk density (grams per cubic centimeter) at age 5.

bulk density increased from 1.40 to 1.46 grams per cubic centimeter but was not affected by a further increase in compaction (table 4). The percentage of sections that were torn decreased as the compaction level decreased. Percentage of torn sections could be an artifact of the sampling or related to the physical strength of the roots. Further evaluation of this variable will be necessary if the meaning of the difference is to be understood.

The compaction and organic-matter removal treatments affected pine height and volume growth by age 6 (table 5). In general, the plot means for volume declined with increased compaction. The same was true for percentage of roots with cortex shedding and periderm formation. When the height and volume of single trees were regressed against root variables for the same trees, no significant relationships were apparent. However, the sampling method does not guarantee that a root sample is from the correct tree.

Table 4—Effect of soil compaction on percentage of roots with cortex shedding and torn sections

Compaction	Bulk density	Cortex shedding	Torn section
	Grams/cm^{-3}	*Percentage*	
None	1.40	52	20
Moderate	1.46	38	18
Severe	1.49	38	10

Table 5—Effect of compaction and organic matter removal on growth of loblolly pine at age 6

Organic matter removal	Compaction treatment	Soil bulk density	Height	Volume
		G/cm^{-3}	*m*	*D*
				m^3/tree
Stem only	None	1.40	5.6	15.8
	Moderate	1.46	5.9	18.3
	Severe	1.49	4.8	9.5
Total tree	None	1.40	4.7	9.2
	Moderate	1.46	5.0	11.0
	Severe	1.49	4.9	11.0
Total aboveground	None	1.40	4.9	9.6
	Moderate	1.46	5.1	10.9
	Severe	1.49	4.4	7.8

Tannin accumulation, pathogenic infection, mycorrhizal status, and formation of lateral roots were unaffected by the soil treatments. These variables have shown promise as indicators of root health in older stands. In this 6-year-old stand, the roots were all generally healthy. Root morphological characteristics that were affected by the compaction, such as periderm formation and number of starch grains per cell, are probably more indicative of tree vigor than of the health of root systems.

CONCLUSIONS

A variety of histological measurements used in the two root samplings significantly separated effects of soil treatments. The variables we measured were easy to tabulate and had relatively low coefficients of variation. Overall, the root health of the trees growing in all soil treatments appeared the same. Cortex shedding and periderm formation, which may be predictors of pine growth, were the only two variables statistically affected by the soil treatments in both sampling periods. Degradation of starch and formation of bark were significantly different by treatment only in the March sampling, while number of starch grains per cell differed by treatment in the October sampling. Soil compaction had a more consistent effect on root morphology than did organic matter removal.

LITERATURE CITED

Allmaras, R.R.; Kraft, J.M.; Miller, D.E. 1988. Effects of soil compaction and incorporated crop residue on root health. Annual Review of Phytopathology. 26: 219-243.

Copeland, O.L., Jr. 1952. Root mortality of shortleaf and loblolly pine in relation to soils and littleleaf disease. Journal of Forestry. 50: 21- 25.

Coutts, M.P. 1987. Developmental processes in tree root systems. Canadian Journal of Forest Research. 17: 761-767.

Feldman, L.J. 1984. Regulation of root development. Annual Review of Plant Physiology. 35: 223-242.

Haas, E. 1980. Fifty diagnostic special stains for surgical pathology. Los Angeles, CA: All-Type Editorial. 86 p.

Kozlowski, T.T.; Scholtes, W.H. 1948. Growth of roots and root hairs of pine and hardwood seedlings in the Piedmont. Journal of Forestry. 46: 750-754.

Leshem, B. 1974. The relation of the collapse of the primary cortex to the suberization of the endodermis in the roots of *Pinus halepensis* Mill. Botanical Gazette. 135: 58-60.

Powers, R.F.; Alban, D.H.; Miller, R.E. [and others]. 1990. Sustaining productivity in North American forests: problems and prospects. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Proceedings of the seventh North American forest soils conference; 1988 July 24-28; Vancouver, BC. Vancouver: University of British Columbia: 49-79.

Sass, J.E. 1951. Botanical microtechnique. 2d ed. Ames, IA: Iowa State College Press. 228 p.

Schmitt, D.; Bower, D. 1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. Res. Note SO-102. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 6 p.

Tiarks. A.E.; Kimble, M.S.; Elliott-Smith, M.L. 1991. The first location of a national, longterm forest soil productivity study: methods of compaction and residue removal. In: Coleman, S.S.; Neary, D.G., comps.,eds. Proceedings of the 6th biennial southern silvicultural research conference; 1990 October 30-November 1; Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 431-442.

Tiarks, A.E.; Powers, R.F.; Alban, D.H. [and others]. 1993. USFS long-term soil productivity national research project: a USFS cooperative research program. In: Kimble, J.M., ed. Proceedings of the eighth international soil management workshop: Utilization of soil survey information for sustainable land use; 1992 July 11-24. Portland OR. U.S. Department of Agriculture, Soil Conservation Service, National Soil Survey Center: 236-241.

Walkinshaw, C.H. 1995. Vulnerability of loblolly pine roots to environmental and microbial stresses. In: Boyd, E.M., ed. Proceedings of the eighth biennial southern silvicultural research conference, 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 354-356.

EFFECT OF A BIOSOLIDS APPLICATION ON PLANTATION LOBLOLLY PINE TREE GROWTH

E. David Dickens and Ansel E. Miller[1]

Abstract—The long-term growth response of a loblolly pine (*Pinus taeda*, L.) plantation to a one-time biosolids application was investigated. The study area was located in the upper Atlantic Coastal Plain on the Savannah River Site in Aiken County, SC. Permanent measurement plots were installed in an 8-year-old loblolly pine stand using a randomized complete block design. Three replications of three treatments (control=0, low=400, and high=800 kilograms TKN per hectare) were assigned on two soil series, Fuquay and Wagram. Biosolids were applied one time in September 1981 at canopy closure. Tree measurements were made at plantation ages 8, 9, 11, 17, and 20 years. Mean diameter, volume per tree, and volume per hectare differences between the control and biosolids plot trees were insignificant until age 11, three growing seasons after biosolids application. Significant mean height differences between the control and biosolids plots did not occur until age 17, nine growing seasons after biosolids application. Merchantable volumes per hectare of the biosolids plot trees were 20 and 30 percent greater than the control's nine growing seasons after biosolids application on the Wagram and Fuquay soils, respectively. Overall, a single biosolids application at canopy closure greatly improved long-term growth of plantation loblolly pine on these soils.

INTRODUCTION

The increased emphasis of the U.S. Congress and the EPA to promote the beneficial land use of biosolids coincides with an interest in increasing forest productivity. Forest soils of the Southeast are generally marginal in fertility. The use of both inorganic commercial fertilizer and biosolids in forest stands has been effective in increasing crop tree growth (Wells and others 1985, McKee and others 1986, NCSFNC 1994). Loblolly pine (*Pinus taeda*, L.) will generally respond to nitrogen and phosphorus inorganic fertilization on better-drained upper coastal plain and Piedmont soils (Hynynen and others 1995). Information is lacking concerning the long-term growth response of loblolly pine to biosolids application (McKee and others 1986). A forest land application of biosolids study was initiated in 1981 on the Savannah River Site to discern the magnitude and duration of growth benefits of loblolly pine due to biosolids application. The differences between control and biosolids plot tree growth parameters through 12 growing seasons after biosolids application will be addressed in this paper.

METHODOLOGY

The study area is located in the upper Atlantic Coastal Plain of Aiken County, SC. Two soil series are present in the study area: the Fuquay soil series (loamy, siliceous, thermic Arenic Plinthic Paleudult) and the Wagram soil series (loamy, siliceous, thermic Arenic Paleudult). The study area was machine planted with nursery-run loblolly pine seedlings at a 1.8- by 3.05-meter spacing in early 1974. Site index for loblolly pine (base age=50 years) is 26.0 meters for the Fuquay and 24.5 meters for the Wagram soil series. The site had previously supported an immature pine stand that was harvested before 1974. The planting had 60 percent survival at age 8 prior to biosolids application. Approximately 55 percent of the trees had fusiform rust (*Cronartium quercum* f. sp. *fusiforme*) cankers on the stems before treatment. Canopy closure was nearly complete at treatment time.

The experimental design employed was randomized complete block with three replications (blocks) per treatment and soil series. Each plot measured 46 by 46 meters. Internal permanent measurement plots were established within each gross plot and were approximately 0.07 hectare in size. Permanent measurement plot trees were assigned a number and tagged with aluminum nails and tags. The loblolly pine stands had about completed their eighth growing season when the liquid biosolids were applied one time in September 1981 by pressure spray guns from tankers. Treatments were as follows: (a) control (no biosolids applied), (b) low liquid @ 400 kilograms TKN per hectare, and (c) high liquid @ 800 kilograms TKN per hectare. The liquid biosolids were anaerobically processed and mainly of domestic origin (80 percent) with an initial pH of 7.3, a carbon:nitrogen ratio of 3:1 and 7.2 percent TKN (dry basis, table 1). Diameter at breast height (d.b.h.) (1.37 meters above groundline), and total height (tht) measurements were taken on all living tagged trees in December 1981 (age 8), March 1983 (age 9), March 1985 (age 11), December 1990 (age 17), and February 1994 (age 20). Total tree volumes were estimated using a stem volume equation (total volume in cubic feet = $0.0014793 * \text{d.b.h.}^{1.821} * \text{tht}^{1.1629}$) developed for site-prepared loblolly pine in the upper coastal plain of Alabama, Georgia, and South Carolina (Bailey and others 1985). These cubic foot volume values were then converted to cubic meter values (cubic meters = cubic feet/35.31). The perimeter of each of the 18 permanent measurement plots was measured and a plot factor for each plot was used to convert from average volume per tree and number of trees to volume per hectare. Diameter at breast height, total height, volume per tree, and volume per hectare averages were tested by year, using analysis of variance and least squares differences at the 5 percent alpha level. Annual

[1] Agricultural and Biological Engineering and Forest Resources Departments, respectively, Clemson University, Box 340357, McAdams Hall, Clemson, SC 29634-0357.

Table 1—Mean concentrations and application levels for liquid biosolids applied to an 8-year-old loblolly pine plantation on the Savannah River Site in Aiken County, SC (Wells and others 1986)

Component	Concentration	Application level low	high
	-----*Percent*----	------ *kg/ha*[a] ------	
Biosolids	2.48[a]	5,555	
11,110			
Ash	46.02	2,556	5,113
Carbon	23.20	1,300	2,600
	----*mg/kg*[a] ----		
Kjeldahl-N	72,374	400	800
NH_4-N	30,361	169	338
NO_3-N	149	0.82	1.64
P	16,209	90	180
K	2,661	15	30
Ca	14,556	81	162
Mg	2,460	14	28
Cu	318	1.8	3.6
Mn	137	0.76	1.52
Zn	1,330	7.4	14.8
Cd	44	0.24	0.48
Ni	44	0.24	0.48

incremental growth between measurement years was also determined to discern if and when control and biosolids plot tree growth was converging.

RESULTS

Topsoil (0 to 15 centimeters) and forest floor nutrient and trace metal rates and distributions 1, 4, and 12 growing seasons after biosolids application are reported elsewhere (Dickens and White 1996). The results (concentrations and kilograms per hectare) were reported across the two soil series as there were no significant soil series (Fuquay versus Wagram) differences. The biosolids-treated plots (low and high levels averaged), when compared to the control at age 20 (12 growing seasons after biosolids application), had 20 percent more surface soil organic matter, 10 percent more total nitrogen, 150 percent more plant-available phosphorus (Bray-P), 45 percent more extractable calcium, and 40 percent more extractable magnesium.

Nitrate-N concentrations were determined from soil solutions collected quarterly from suction lysimeters installed in all plots to a 1-meter depth. The peak soil solution nitrate-N concentration in the low-level plots was 4.8 milligrams per liter, occurring 6 and 12 months after biosolids application and returned to background levels (< 1.0 milligrams per liter) within 2 years (Wells and others 1986). The high biosolids level plots' nitrate-N peak concentration (at 1 meter in soil solution) was 21 milligrams per liter, occurring 15 months after application, and returned to background levels 24 months after application. Two groundwater wells, one upgradient and one downgradient of the study area, were also installed to a depth of 13 meters. These wells were monitored quarterly for 6 years. Results of all analyses indicate no groundwater degradation as a consequence of the biosolids treatments (Lower 1985, unpublished data). The mean nitrate-N concentration for the upgradient well was 0.70 milligrams per liter and for the downgradient well was 1.8 milligrams per liter. The maximum nitrate-N values were below the 10 milligrams per liter maximum contaminant level.

There were no significant tree diameter (@ 1.37 meters above groundline) differences among the three treatment levels at stand age 9 years, one full growing season after biosolids application (fig. 1-A). Loblolly pine mean diameters grown on the biosolids plots were significantly

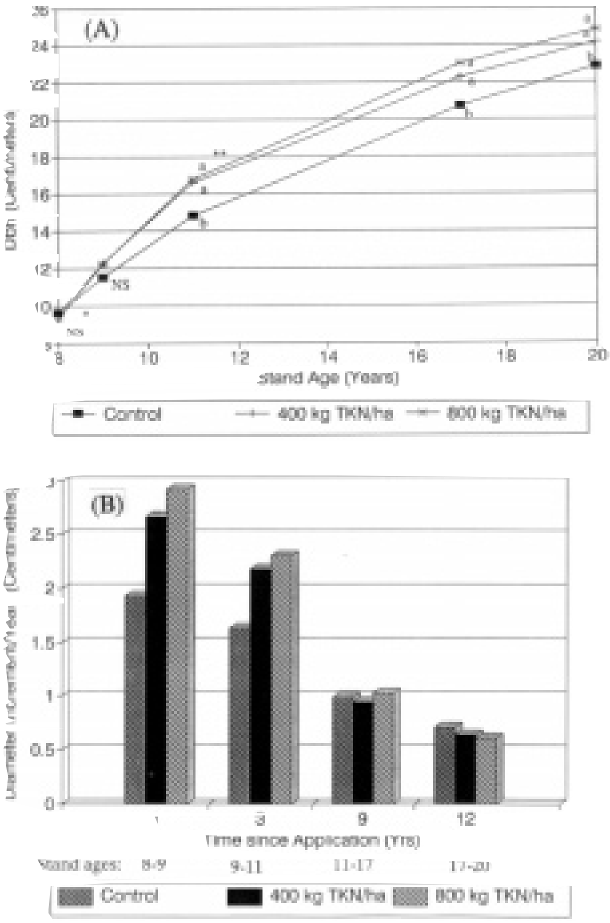

Figure 1—Mean diameter (d.b.h.) at stand age (A) and (B) annual incremental growth between stand ages in a loblolly pine plantation after biosolids application on the Savannah River Site in Aiken County, SC.

*NS = Not significant using LSD at the 5 percent alpha level.
**Within same year, means followed by the same letter are significantly different.

greater, by 1.81 and 2.01 centimeters, than on the control plots at age 11, three growing seasons after biosolids application. The maximum diameter difference between the two different biosolids rates and the control occurred at different times. The maximum diameter difference between the low biosolids level and control plot trees (1.81 centimeters) occurred at age 11, three growing seasons after biosolids application. The maximum difference between the high biosolids and control plot trees (2.27 centimeters) occurred at age 17, nine growing seasons after biosolids application. The biosolids plot mean tree diameter at age 17 years (22.6 centimeters) was approximately equal to the mean control plot average tree diameter (22.8 centimeters) at age 20 years, thus reducing the potential rotation age by 3 years with a single biosolids application. Tree diameter annual increment (diameter growth between sampling dates) differences between the biosolids plot trees and the control plot trees were greatest between ages 8 and 9 (38 percent and 51 percent greater; fig. 1-B). The control plot trees' diameter annual increment exceeded the low biosolids increment for the period between ages 11 and 17, and the high biosolids tree diameter increment between ages 17 and 20. The mean diameter for the control plot trees (22.86 centimeters) was still significantly less than both biosolids levels tree mean diameters (24.14 and 24.83 centimeters for the low and high levels, respectively) by age 20, 12 growing seasons after the one-time biosolids application.

Initially (ages 8 and 9 years) the mean total heights of high biosolids plot-grown loblolly pine trees were significantly less than the control's (fig. 2-A). Three growing seasons after biosolids application (age 11) there were no significant height differences between the three treatment means. The low and high biosolids plot trees' total height means were significantly greater than the control's at age 17 (an average of 0.70 meters taller) and age 20 (0.38 meters greater). Loblolly pine height growth annual increment was greater for biosolids plot-grown trees than the control's for the sampling periods between stand ages 9 to 11 and 11 to 17 years. The height growth annual increment for the control plot trees was greater than the biosolids plot trees between ages 17 and 20 (fig. 2-B).

There were no significant mean-total-volume-per-tree (cubic meters per tree) differences between the three treatment levels at the first two sampling dates (ages 8 and 9 years, fig. 3-A). The biosolids plot-volume-per-tree means were significantly greater (21 and 27 percent greater) than the control's at age 11, 3 growing seasons after biosolids application. Mean volume-per-tree values for the biosolids plot-grown trees continued to be significantly greater than the control's at ages 17 and 20. The percent difference between the biosolids plot volume-per-tree and the control's was decreasing after 1985 (age 11) to 18 and 26 percent at age 17 and 11 and 19 percent at age 20 (control versus the low and high biosolids, respectively). Total volume-per-tree annual increment between measurement years increased for all three treatment levels from age 8 through age 11 years. The low and high biosolids plot volume-per-tree annual increment was greater than the control's between ages 8 and 9, 9 and 11, and 11 to 17 (fig. 3-B). Maximum volume-per-tree annual increment differences between the biosolids and control plot trees appears to have occurred between ages 9 and 11.

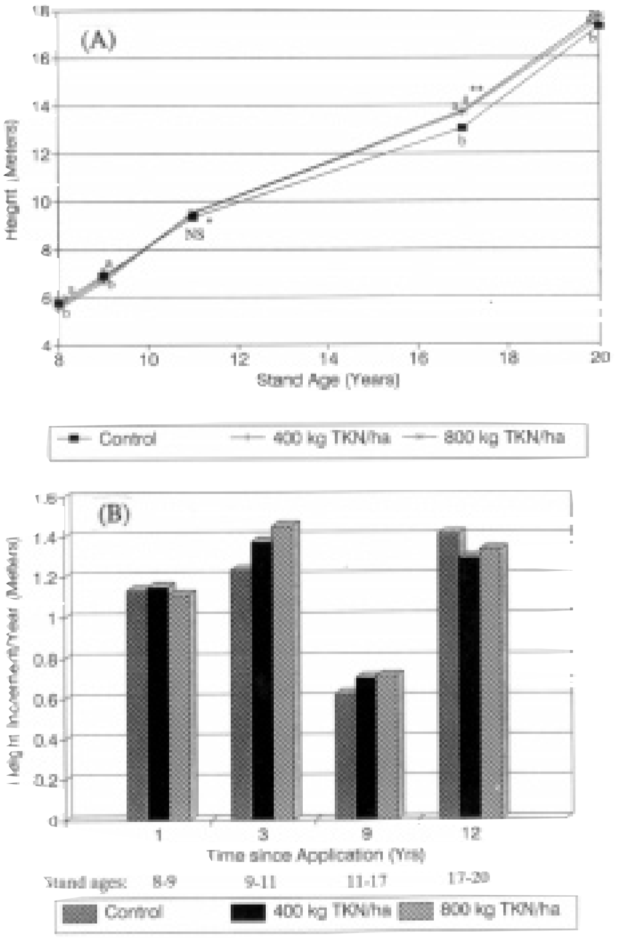

Figure 2—Mean height at stand age (A) and (B) annual incremental growth between stand ages in a loblolly pine plantation after biosolids application on the Savannah River Site in Aiken County, SC.

*NS = Not significant using LSD at the 5 percent alpha level.
**Within same year, means followed by the same letter are significantly different.

Mean total volume-per-hectare values (cubic meters per hectare) were not significantly different for the three treatment levels at ages 8 and 9 years (fig. 4-A). The biosolids plots' tree volume-per-hectare means were significantly greater than the control's at ages 11, 17, and 20. The greatest total volume percent difference between the low level and control was 22 percent occurring at age 17 years, and 26 percent between the high level and control occurring at age 11 years. Tree losses to a beetle spot infestation between 1985 and 1990 in one of the high-level plots reduced the number of trees, reducing high-level mean-volume-per-hectare at age 17. The total volume-per-hectare annual increments for all treatment levels increased between stand ages 8 to 9 and 9 to 11 years. The biosolids plot volume-per-hectare annual increment was greater than

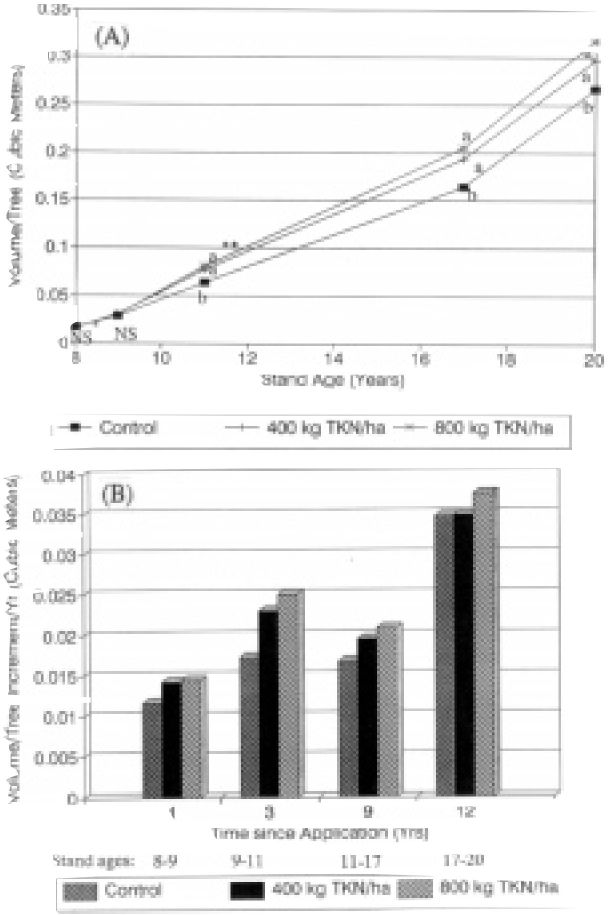

Figure 3—Mean volume per tree at stand age (A) and (B) annual incremental growth between stand ages in a loblolly pine plantation after biosolids application on the Savannah River Site in Aiken County, SC.

*NS = Not significant using LSD at the 5 percent alpha level.
**Within same year, means followed by the same letter are significantly different.

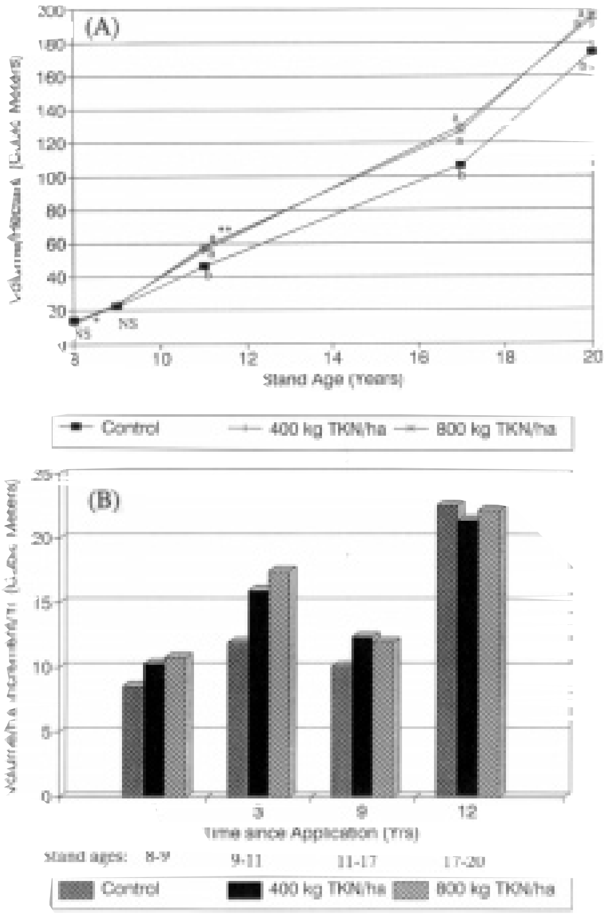

Figure 4—Mean volume per hectare at stand age (A) and (B) annual incremental growth between stand ages in a loblolly pine plantation after biosolids application on the Savannah River Site in Aiken County, SC.

*NS = Not significant using LSD at the 5 percent alpha level.
**Within same year, means followed by the same letter are significantly different.

the control's between 8 and 9, 9 and 11, and 11 to 17 (fig. 4-B). The maximum volume-per-hectare annual increment differences between the biosolids plot and control plot trees appears to have occurred between ages 9 and 11.

DISCUSSION AND CONCLUSIONS

The one-time application of biosolids in an 8-year-old loblolly pine stand proved beneficial by increasing loblolly pine tree growth (over non-biosolids plot tree growth). Loblolly pine growth response to the biosolids appears to be somewhat similar to that of inorganic fertilizer. Hynynen and others (1995) found loblolly pine growth response to inorganic fertilizer peaked 4 years after one-time application at levels of 110, 220, and 330 kilograms of nitrogen per hectare (with 28 to 56 kilograms phosphorus per hectare). The maximum growth differences between the three levels and control were 14, 24, and 34 percent occurring 4 to 6 years after fertilization. Biosolids plot volumes per hectare were 21 to 26 percent greater than the control's at age 11 years, three growing seasons after biosolids application and 19 to 22 percent greater than the control's at age 17 years, nine growing seasons after biosolids application.

Total volume per tree (fig. 3-B) and volume per hectare (fig. 4-B) annual increment between ages 11 and 17 were less than those between ages 9 and 11 years. If maximizing wood yield is a primary objective, a thinning, with or without a second biosolids application, may be feasible between these years. Palmer drought index numbers (Palmer 1965, unpublished data 1997) between stand ages 11 and 17 (February 1985 to December 1990) indicated more prolonged and severe growing season droughts for the Savannah River area than the measurement period before 1985 or after 1990. Extended growing season droughts between stand ages 11 and 17 (1985 to 1990) may explain the reduction in annual height, volume per tree, and volume per hectare growth. Increasing available soil moisture, sunlight, and nutrients to the more dominant residual trees, by thinning, may increase the annual volume growth.

Merchantable volume (to a 7.5 centimeter top inside bark) per hectare in the low biosolids plots was 20 percent greater than the control on the Wagram soil and 30 percent greater than the control on the Fuquay soil nine growing seasons after biosolids application on the Savannah River (Dickens 1993). The averaged merchantable wood increase due to biosolids application after nine growing seasons (age 8 to age 17 years) accounts for a $500 per hectare return increase (at $35 per cord).

ACKNOWLEDGMENT

The authors would like to thank the USDA Forest Service for supporting this project.

LITERATURE CITED

Bailey, R.L.; Grider,G.L.; Rheney, J.W.; Pienaar, L.V. 1985. Stand structure and yields for loblolly pine plantations in the piedmont anD upper coastal plain of Alabama, Georgia, and South Carolina. University of Georgia Research Bulletin 328. 118 p.

Dickens, E.D. 1993. Beneficial uses of biosolids on forest land. Extension Circular 679. Clemson, SC: Clemson University. 4 p.

Dickens, E.D.; White R.K. 1996. Elemental distribution in the forest soil and floor of loblolly pine stands after biosolids application. In: Proceedings of the tenth annual residuals and biosolids Management Conference, Denver, CO. Alexandria, VA: Water Environment Federation: 10-19.

Hynynen, J.; Burkhart, H.E.; Allen, H.L. 1995. Modeling tree growth in fertilized midrotation loblolly pine plantations. Report 80. Blacksburg, VA: Virginia Polytechnic Institute and State University, School of Forestry and Wildlife Resources. 12 p.

McKee, W.H., Jr.; McLeod, K.W.; Davis, C.E. [and others]. 1986. Growth response of loblolly pine to municipal and industrial sewage sludge applied at four ages on upper coastal plain sites. In: Cole, D.W.; Henry, C.H.; Nutter, W.L., eds. The forest alternative for treatment and utilization of municipal and industrial wastes. University of Washington Press, Seattle and London: 272-291.

NCSFNC. 1994. North Carolina State Forest Nutrition Cooperative twenty-third annual report. Raleigh, NC: North Carolina State University, College of Forest Resources. 31 p.

Palmer, W.C. 1965. Meteorlogical drought. U.S. Department of Commerce Research Paper 45. Washington, DC: U.S. Weather Bureau, Office of Climatology. 58 p.

Wells, C.G.; McLeod, K.W.; Murphy, C.E. [and others]. 1985. Response of loblolly pine plantations to two sources of sewage sludge. In: Proceedings, TAPPI Research and Development Conference. Atlanta, GA: TAPPI Press: 85-94.

Wells, C.G.; Murphy, C.E.; Davis, C.E. [and others]. 1986. Effect of sewage sludge from two sources on elemental flux in soil solution of loblolly pine plantations. In: Cole, D.W.; Henry, C.H.; Nutter, W.L., eds. The forest alternative for treatment and utilization of municipal and industrial wastes. University of Washington Press, Seattle and London: 154-167.

PELLETIZED CHICKEN LITTER AS A NUTRIENT SOURCE FOR PINE ESTABLISHMENT IN THE GEORGIA COASTAL PLAIN

Parshall B. Bush, William C. Merka, and Lawrence A. Morris[1]

Abstract—A series of three loblolly pine (*Pinus taeda* L.) regeneration plots were established in the Georgia coastal plain to evaluate chicken litter as a potential phosphorus source for pine regeneration. Treatments consisted of (1) standard fertilization with diammonium phosphate, (2) broadcast of litter at 1 ton per acre, (3) control, (4) 0.5 pounds per tree at planting, (5) 1.0 pounds per tree at planting, and (6) 3.3 pounds per tree at planting.

Chicken litter broadcast at a rate of 1 ton per acre produced greatest pine growth response. Early pine mortality was observed on one wet site. A greenhouse study of the value of poultry manure stabilized with a high carbon:nitrogen ratio primary sludge from a Kraft paper mill shows that mixtures have potential as slow-release nutrient sources. Fresh mixtures of the two materials retain some adverse properties that lead to poor seedling survival in soils amended with fresh poultry manure.

Litter application cost of approximately $9.25 per ton compares favorably with the estimated $29 per acre for diammonium phosphate.

INTRODUCTION

Georgia's forest and poultry industries are two of the largest industries in the State, contributing an estimated $26 billion to the annual economy and directly employing 175,000 workers (Georgia Forestry Commission 1995, Mauldin and others 1993). Favorable soil and climatic conditions and the availability of rural expanses in the State have fostered the development and success of these two industries. The annual production of approximately one billion birds generates 1.5 million tons of litter. The recent expansion of the poultry industry into south Georgia has generated concern over waste and nutrient management on sandy coastal plain soils.

The potential use of poultry litter as a fertilizer source is limited by: (1) low nutrient density, (2) low bulk density, and (3) nonuniformity. Because of its low nutrient/bulk density, cost of transportation of this material is high. Previous work at The University of Georgia[2] has determined that a blend of fine fraction/middle fraction litter material produces a better pellet and requires much less energy than pellets made from the raw (whole) litter. By separating the litter fractions prior to pelleting, the mill was also able to (1) decrease the material flow through a hammermill process, reducing energy costs and reducing maintenance on the hammermill itself, and (2) produce a uniform product with a nutrient (N, P_2O_5, K_2O) analysis of 4.6, 3.9, and 2.9 percent, respectively.

Since phosphorus (P) is often a limiting nutrient in coastal plain forested pine stand establishment, it is of interest to attempt to utilize chicken litter as a P source during stand establishment. In addition to supplying the P requirement, the litter would also supply some other essential elements for pine growth. Previous attempts at broadcast application of chicken litter at stand establishment have resulted in aggravated weed problems. Since intensive pine silviculture prescriptions include weed control, a study was established in the coastal plain to evaluate graded levels of chicken litter as a nutrient source.

Use of pelleted chicken litter as a fertilizer source for pine establishment could produce (1) a new market for a waste product (chicken litter), (2) a balanced fertilizer source, (3) a minimal impact on soil micro/macro organisms and on the environment, (4) savings in fertilizer costs to the forest industry, and (5) new jobs and/or increased profits for the rural poultry and timber producers.

The use of poultry litter as the P source at stand establishment in this region was evaluated. The project compares the growth rate of pine seedlings fertilized with poultry litter at four different rates to seedlings fertilized with commercial fertilizers presently used in intensive pine silviculture. Test plots were established in the coastal plain counties of Bulloch, McIntosh, and Tattnall.

The addition of mixtures of pulp mill sludge and poultry litter was evaluated for use as fertilizer for stand establishment. Primary sludge from pulp and paper production largely consists of organic fiber with varying amounts of inorganic fillers. Its high carbon (C) and low N content can result in N deficiencies when used in land application programs. An alternative to direct application of primary sludge is to produce a nutritionally balanced and more easily handled product by combining these sludges with animal wastes having higher N contents, such as poultry litter. For instance, primary sludge with a C:N ratio of 100:1 can be combined with poultry litter with C:N ratios of 5:1 to produce a slow-release fertilizer with initial C:N ratios of 25:1. Ash generated from combustion of wood wastes can also be combined in the mixture for odor reduction and as a means of improving overall nutritional value.

---

[1] Professor, Department of Poultry Science, Agricultural Services Laboratories; Associate Professor, Department of Poultry Science; and Associate Professor, Daniel B. Warnell School of Forest Resources, The University of Georgia, Athens, GA 30602 (respectively).

[2] Unpublished data. William C. Merka, Associate Professor, Department of Poultry Science, The University of Georgia, Athens, GA 30602.

As part of an ongoing School of Forest Resources study on mill residue utilization, noncomposted mixtures of primary mill sludge and poultry litter were evaluated in a greenhouse study. Growth was measured following application and compared with growth on experimental plots amended with sludge and commercial fertilizer. Foliage samples were collected to assess nutritional benefits of applications.

PROJECT PURPOSE AND OBJECTIVES

The major objectives of this study were to:

1. Determine whether pelleted poultry litter can be used as a fertilizer source for pine seedling establishment in the Georgia coastal plain.
2. Compare graded levels of poultry litter pellet applications (0, 0.5, 1.0, and 3.3 pounds per seedling) to current stand fertilization practices.
3. Evaluate mixtures of poultry litter and primary sludge from a pulp and paper mill for its uses as fertilizer in newly established loblolly pine (*Pinus taeda* L.) plantations.
4. Prepare an economic assessment of the use of poultry litter in terms of the cost savings to the forest industry.

Field Study (Objectives 1 and 2)

Two field studies were established in 1995 on Union Camp sites in McIntosh and Tattnall Counties, GA. The experimental design for each consisted of six treatments and three replications. An additional study was established (two soil types x six treatments x two replications) in 1996 in Bulloch County. Tree spacing at these sites was 6 by 12 feet (approximately 600 trees per acre). Plots consisted of 7 trees in each of 7 adjacent rows (49 trees per plot).

Treatments consisted of the following:

1. No litter or chemical fertilizer applied (control).
2. Litter applied at 0.5 pounds per seedling (9 pounds P_2O_5 per acre).
3. Litter applied at 1.0 pounds per seedling (18 pounds P_2O_5 per acre).
4. Litter applied at 3.3 pounds per seedling (60 pounds P_2O_5 per acre).
5. Litter broadcast at 1 ton litter per acre (60 pounds P_2O_5 per acre).
6. Fertilization at the operational rate (125 pounds diammonium phosphate per acre: 18, 46, 0; 58 pounds P_2O_5 per acre).

For the 0.5 and 1.0 pounds per seedling rate, litter was applied in dibble holes drilled on opposite sides of each seedling, approximately 12 inches from the seedling. For the 3.3 pounds per seedling rate, litter was applied in four dibble holes drilled at right angles from each other, approximately 12 inches from the seedling. Although the fertilizer tag showed an analysis of 4, 3, 2, analysis of the litter indicated a fertilizer equivalent of 4.0, 4.1, 4.0. Tree growth was assessed 12 months after the initial fertilization. Growth was compared among all treatments and results were analyzed by ANOVA at the 0.05 level of significance.

Extensive pine mortality was observed on the poorly drained Bladen soil site, which exhibited survival rates of 97.3 percent with standard fertilization, 95.3 percent with broadcast, 90.9 percent with the control, 86.4 percent with 0.5 pounds per acre, 75.1 percent with 1 pound per acre, and 60.0 percent with 3.3 pounds per acre. Pine survival (all treatments >95 percent) and growth on the well-drained Ludowici, GA, site characterized by Chipley soils was excellent. Pine mortality on the Bladen soils appeared to be more severe in the wetter portions of the site. One might speculate that under the anaerobic conditions encountered on the wet site, ammonia buildup occurred to toxic levels at high litter application rates. Surviving trees on these plots were the largest trees in the study area. Since these sites received extensive weed control, there was no evidence of enhanced weed competition.

Field study results from the Bladen and Ludowici sites (1995) indicate that broadcast application of pelletized chicken litter at a rate of 1 ton per acre produced significantly greater growth (tree height) and root collar diameter than in standard commercial fertilization treatment or the control (tables 1 and 2). Evaluation of the Ludowici site at the end of the second growing season (table 2) showed that treatment-related differences carried through year 2. Unexpectedly, there was no difference in growth between the control and commercial fertilization treatment. Plant tissue analysis did reflect an increase in P from

Table 1—Evaluation of 1-year pine growth on the Bladen, GA, site

Treatment	Observations	Height	Root collar diameter
	Number	*Feet*	*Inches*
Standard fertilization	154	2.94A[a]	0.72B
Broadcast (1 ton/ac)	155	3.03A	0.82A
Control	159	2.98A	0.76AB
0.5 lbs/tree at planting	128	3.14A	0.78AB
1.0 lbs/tree at planting	112	2.83A	0.77AB
3.3 lbs/tree at planting	99	2.93A	0.77AB

Site 1: Miller #1 Tract, McIntosh County, near Bladen, GA (N of Brunswick along Warsaw Road near intersection of Warsaw Road and Brookston Road). Soil type: Bladen series soils are very deep, poorly drained, slowly permeable soils that formed in thick beds of acid clayey sediments on fluvial or marine terraces. Slopes range from 0 to 2 percent. Mean annual precipitation is ~50 inches and mean annual temperature is ~69 ^{o}F. Plot design: six treatments, three replications per treatment. Pretreatment soil test results: pH=4.7-5.1; P=6.2-13.9 lbs/ac; K=37-81 lbs/ac; N=0.045-0.070 percent N.

[a] Means in the same column followed by the same letter are not significantly different using the Duncan Multiple Range Test.

Table 2—Evaluation of 1 and 2-year pine growth on the Ludowici, GA, site

Treatment	Observations Yr 1	Observations Yr 2	Height Yr 1	Height Yr 2	Root collar diameter Yr 1	Root collar diameter Yr 2
	----Number----		--------*Feet*--------		----------*Inches*-----------	
Standard fertilization	162	147	2.47 C[a]	5.24 C	0.82 B	1.68 C
Broadcast (1 ton/ac)	145	141	2.99 A	5.81 A	0.94 A	1.94 A
Control	158	150	2.57 C	5.29 C	0.86 B	1.68 C
0.5 lbs/tree at planting	147	140	3.00 A	5.61 AB	0.91 A	1.80 B
1.0 lbs/tree at planting	139	134	2.88 AB	5.54 B	0.91 A	1.79 B
3.3 lbs/tree at planting	150	147	2.81 B	5.53 B	0.91 A	1.80 B

Site 2: Near Ludowici, GA, Long County (along Magnolia Road just past intersection with Kings Road). Soil type: Chipley series soils are very deep, moderately well-drained to somewhat poorly drained, rapidly permeable soils that formed in thick deposits of sandy marine sediments. They are on uplands in the lower coastal plain. Slopes range from 0 to 2 percent. Plot design: six treatments, three replications per treatment. Pretreatment soil test results: pH=4.8 to 5.1; P=6.2 to 14.1 pounds per acre; K=29.3 to 59 pounds per acre; N=0.030 to 0.041 percent N.

[a] Means in the same column followed by the same letter are not significantly different using the Duncan Multiple Range Test.

fertilization on the standard fertilization site. Plant tissue analysis pooled from both sites revealed no treatment-related effects in nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, boron, or zinc content (data not presented). The significant differences in tissue aluminum values can be attributable to alterations in root zone soil pH or contamination of some tissues by aluminum-containing soil. Commercial fertilization tended to elevate tissue copper levels. This is somewhat surprising in light of anticipated elevated copper levels normally associated with chicken litter.

Pine survival (>95 percent) and growth on the well-drained Ludowici, GA, site characterized by Chipley soils was excellent (table 2). Evaluation of plant tissue analysis from the Ludowici site by itself revealed that chicken litter treatments elevated the foliar phosphorus levels and that this increase was significant in the second-year postplant (table 3). Although all treatments were in the sufficiency range, a linear increase in phosphorus foliage content with increasing chicken litter treatment level was observed. The chicken litter did, therefore, serve as a phosphorus source. In general, the broadcast treatment was as good as the in-hole treatments.

Foliar nitrogen levels did not increase with increased litter level. All foliar nitrogen levels, including the control, were in the sufficiency range. If there was any benefit from the nitrogen, we are not seeing it at the 1-year evaluation. The foliar potassium levels were all within the sufficiency range and only the 3.3 pounds per tree rate increased the level above the control (table 3).

An additional set of plots was established in 1996 on a site near Oliver, GA, that has wet soils (Albany soil series) and relatively well-drained soils (Blanton soil series). The Oliver site evaluation consisted of six treatments x two soil types x two replications. Survival was good on both soil types (>95 percent). Again the broadcast application of chicken litter at a 1 ton per acre rate produced the greatest growth, followed by 3.3 pounds per tree, 1 pound per tree, control, 0.5 pounds per tree and standard fertilization (table 4). There was significant interaction between the soil type and tree growth, with the greatest growth occurring on the Albany soil. Plant tissue analysis conducted on 1-year foliar samples showed no significant differences in nitrogen, phosphorus, potassium, magnesium, manganese, iron, aluminum, boron, calcium, or copper. Nutrients were in the sufficiency range.

Response of Greenhouse-Grown Seedlings to the Poultry Manure Addition (Objective 3)

In an earlier study[3], survival of greenhouse-grown loblolly pine seedlings was poor following application of fresh poultry manure. Foliage symptoms were consistent with ammonium toxicity, suggesting the potential value of

[3] Unpublished data. Lawrence A. Morris, Associate Professor, Department of Poultry Science, The University of Georgia, Athens, GA 30602.

Table 3—Plant tissue analyses for Year 1 and Year 2 of pine regeneration/chicken litter study at the Ludowici, GA, site

Treatment[a]	Nitrogen Yr 1	Nitrogen Yr 2	Phosphorus Yr 1	Phosphorus Yr 2	Potassium Yr 1	Potassium Yr 2
	Percent					
Standard	1.66A[b]	1.39A	0.135ABC	0.114 B	0.508AB	0.436A
Broadcast	1.55AB	1.36A	0.136ABC	0.128AB	0.545AB	0.494A
Control	1.43AB	1.37A	0.123 C	0.115AB	0.469 B	0.439A
0.5 lbs	1.45AB	1.35A	0.128 BC	0.121AB	0.515AB	0.463A
1.0 lbs	1.28 B	1.31A	0.140AB	0.113 B	0.517AB	0.484A
3.3 lbs	1.44AB	1.36A	0.145A	0.138A	0.536A	0.482A

[a] Standard=Standard fertilization; Broadcast=Broadcast (1 ton per acre); 0.5=0.5 pounds per tree at planting; 1.0=1.0 pounds per tree at planting; 3.3=3.3 pounds per tree at planting.
[b] Means in the same column followed by the same letter are not significantly different using the Duncan Multiple Range Test.

Table 4—Evaluation of 1-year pine growth on the Oliver, GA (near Statesboro) site

Treatment	Observations Albany	Observations Blanton	Height Albany	Height Blanton	Root collar diameter Albany	Root collar diameter Blanton
	Number		*Feet*		*Inches*	
Standard fertilization	122	121	3.08 C[a]	3.08ABC	0.90 BCD	0.90AB
Broadcast (1 ton/ac)	97	101	3.56A	3.10ABC	0.99 A	0.96A
Control	152	97	3.26 BC	2.96 C	0.86 D	0.87 B
0.5 lbs/tree at planting	94	96	3.09 C	3.24A	0.87 CD	0.93AB
1.0 lbs/tree at planting	95	97	3.36AB	3.23AB	0.93ABC	0.91AB
3.3 lbs/tree at planting	95	92	3.59A	2.98ABC	0.96AB	0.87 B

Site 3: Near Oliver, GA, Bulloch County. Soil types: Albany and Blanton series. The Blanton series consists of deep, moderately well-drained, very strongly acid soils of the coastal plain (slopes 0 to 5 percent). The soils are low in fertility and contain little organic matter. Albany series consists of very deep, somewhat poorly-drained soils that formed in coastal plain deposits of sandy material underlain by loamy sediments (slopes 0 to 6 percent). Permeability is rapid in the thick sandy surface horizon and moderate to moderately slow in the loamy subsoil. Plot design: two soils, six treatments, three replications per treatment. Pooling data for site produced significant treatment, soil, and treatment-by-soil interaction for tree height. Only treatment effects were significant for root collar diameter.
[a] Means in the same column followed by the same letter are not significantly different using the Duncan Multiple Range Test.

reducing initial nitrogen availability in low C:N ratio poultry manure by combining it with high C:N ratio materials prior to use as a soil amendment.

A greenhouse study of the value of poultry manure stabilized with a high C:N ratio primary sludge from a Kraft paper mill was conducted as part of a larger study of the use of paper mill residues as soil amendments. The entire study consisted of 23 organic and inorganic paper mill residues applied at two levels to two soil types in four complete blocks. Four of these treatments were of interest to this study of poultry manure. These are: the unamended control; primary sludge (0.068, 0.09) applied alone; primary sludge combined with poultry manure (4.7, 1.3, 2.2) in a

3.25:1 ratio to achieve a final C:N ratio of 20:1; and Black Kow® (0.5, 0.49, 0.50), a commercially available organic amendment derived from cow manure and wood bark. Low (71 grams per pot) and high (425 grams per pot) rates of each residue, which corresponded to a field rate of 10 and 60 dry tons per acre, were mixed with surface soil (a horizon material) from two soil series widely used for pine plantations (Leon and Orangeburg). Following residue addition, loblolly pine seedlings from four half-sib families that had been lifted from planting beds and acclimated to the greenhouse for 4 weeks were planted in 350 cubic inches plastic pots (two seedlings per pot). Pots were spatially arranged on greenhouse benches to provide four family blocks split into the two soil types. Amendment type and level were located at randomly selected positions within the soil type main plots. Blocking the experiment in this manner minimized differences associated with position within the greenhouse and limited the possibility of an accident causing loss of several replications of one or more treatments. Family effects were confounded with blocks and no family treatment interaction evaluations were possible.

At the start of the experiment, seedlings averaged 20.9 centimeters in height and soil pH averaged 5.5 and 5.4 for Leon and Orangeburg soils, respectively. Following planting in August 1995, seedlings were grown under well-watered conditions for 5 months without additional fertilizer addition. In January 1996, seedling height and diameter were measured and seedlings harvested and separated into branch and foliage components. Foliage and branches were dried and ground prior to analysis for nitrogen, phosphorus, potassium, calcium, and magnesium concentration.

Seedling size at the end of the 5-month experimental period is provided in table 5. Seedling survival was decreased by the high rate of the poultry manure-primary sludge amendment on both soil types. Large impacts on survival were not observed for the low application rate. For the Leon soil, seedling height and diameter (data not shown) were dramatically increased at the low addition rate of the poultry manure-primary sludge mixture, a response that was not as obvious at the high rate of addition. The few seedlings that survived the high rate of addition of this mix in Orangeburg soils were also larger than seedlings in the control, primary sludge, or Black Kow® treatments.

Foliage nutrient concentrations (table 6) indicate that by the time the experiment was harvested, seedlings in all treatments were deficient in nitrogen. Seedlings in the poultry manure-primary sludge mixture had the highest overall concentrations of nitrogen, phosphorus, potassium, calcium and magnesium in foliage. This indicates that poultry manure-primary sludge mixtures have potential value as a slow-release nutrient source but fresh mixtures of the two materials retain some adverse properties leading to poor seedling survival in soils amended with fresh poultry manure. This survival problem may be reduced or eliminated by allowing poultry manure-primary sludge mixtures to compost for a period prior to application to young seedlings or by reducing application rates.

Economic Assessment (Objective 4)

For poultry litter to be adopted as a nutrient source for pine seedlings, it must cause increase in growth greater than or equal to the standard fertilization practice of applying 125 pounds of diammonium phosphate (18, 46, 0) and the cost of procuring, transporting, and applying litter must be equal to or less than the cost of procuring and applying diammonium phosphate.

At $270 per ton for diammonium phosphate (local dealer price), an application rate of 125 pounds per acre would cost $16.85. Application would add an additional $12 per acre.

Table 5—Survival and mean height of surviving seedlings grown in soil amended with three organic residues for 5 months

Amendment	Rate	Leon soil survival	Leon soil height		Orangeburg soil survival	Orangeburg soil height	
		Percent	*Centimeters*		*Percent*	*Centimeters*	
Unamended control		100	19.2	(4.5)[a]	94	25.8	(5.0)
Primary sludge	Low	100	20.9	(4.4)	88	23.4	(5.9)
	High	62	23.2	(6.4)	100	23.1	(2.9)
Primary sludge+poultry manure	Low	100	36.4	(5.9)	88	22.2	(6.8)
	High	25	26.0	(2.8)	38	31.3	(11.5)
Black Kow®	Low	100	23.5	(5.6)	100	25.9	(4.9)
	High	100	25.6	(6.6)	100	27.0	(9.0)

[a] Standard deviation.

Table 6—Foliage nutrient concentrations of seedlings grown in soil amended with three organic residues for 5 months; results averaged across two application rates

Amendment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Percent				
Unamended control	0.63	0.12	0.54	0.34	0.14
Primary sludge	0.94	0.10	0.63	0.44	0.19
Primary sludge+poultry manure	1.00	0.11	0.77	0.45	0.18
Black Kow®	0.84	0.14	0.76	0.30	0.14

Therefore, the total cost of aerial application of 125 pounds of diammonium phosphate would be $28.85 per acre.

In areas of North Georgia where poultry litter is readily available, haulers will spread litter for $25 per 6-ton truckload plus $1 per mile of hauling cost from the growing house to the application site. Using an application rate of 1 ton per acre as a nutrient source for pine seedlings, the litter would cost $4.17 per acre plus hauling cost. Each additional mile of hauling would increase per-acre cost by 17 cents. Experience shows that 20 to 25 miles would be a maximum haul of whole litter. This would result in a total litter cost of $8.44 per acre. A county agent in a southeastern Georgia poultry county reported that spread litter costs $5 per ton plus hauling costs. This greater cost of litter in southeastern Georgia would increase the per-acre cost to $9.25. Using poultry litter to fertilize pine seedlings is a nontraditional use of this material. Field trials should be conducted to determine the accuracy of these cost calculations.

Factors limiting the use of poultry litter may include:

1. Could traditional spreader trucks operate in tree plantings? Transfer of litter from trucks to a specialized spreading device would increase costs.
2. Would an increased demand for litter in areas of lesser poultry production cause the cost of litter to increase?
3. Would the convenience of procurement and aerial application of diammonium phosphate offset the cost savings of using poultry litter?

These and other factors should be evaluated prior to deciding to use poultry litter as a nutrient source for pine seedlings.

SUMMARY

Field studies conducted in the Georgia Coastal Plain indicate that pelletized chicken litter applied at a rate of 1 ton per acre did serve as a phosphorus source for pine stand establishment. Pine seedling mortality was observed on the poorly drained wet site associated with the higher treatment rates; one might speculate that anaerobic conditions may lead to excessive ammonia buildup. Leaf tissue nitrogen levels did not increase with increased litter level. The greenhouse study indicates that poultry manure-primary sludge mixtures have potential value as a slow-release nutrient source, but that fresh mixtures of the two materials retain some adverse properties that lead to poor seedling survival in soils amended with fresh poultry manure. This survival problem may be reduced or eliminated by composting poultry-primary sludge mixtures prior to application. Economic analysis indicates that chicken litter applied at a rate of 1 ton per acre would cost $8.44 to $9.25 per acre. This compares favorably with the current diammonium phosphate application cost of $29 per acre. Weed control measures currently used in intensive stand management would minimize the potential increase in weed populations from litter applications.

ACKNOWLEDGMENT

The authors wish to thank the Georgia Forestry Commission for their financial and technical support.

LITERATURE CITED

Georgia Forestry Commission 1995. The importance of forestry to Georgia: a 1995 report. Macon, GA: Georgia Forestry Commission.

Mauldin, J.M.; Lacy, M.P.; Savage, S.I. 1993. Georgia poultry survey. Special Extension Publication. Athens, GA: Cooperative Extension Service, The University of Georgia.

EFFECT OF FERTILIZATION AND HERBACEOUS WEED CONTROL ON FIRST-YEAR SURVIVAL, GROWTH, AND TIP MOTH INCIDENCE ON LOBLOLLY PINE IN A SANDHILL SOIL

John L. Torbert and Polly-Anne Rantis[1]

Abstract—Although loblolly pine (*Pinus taeda* L.) productivity is often poor on Sandhill soils, these areas can be strategically important to forest industry because of the ability to log them during wet weather. A study was established on a deep, excessively well-drained sandy soil (Lakeland soil series) to test the effects of herbaceous weed control (control vs. 24 ounce VelparL) factorially combined with three fertilizer treatments (control, 250 pounds (lbs) diammonium phosphate per acre, and a "complete" fertilizer with 350 lbs micronutrient blend + 330 lbs ammonium nitrate per acre) on loblolly pine growth and pine tip moth (*Rhyacionia spp*.) incidence using a complete randomized design with three replications. Hexazinone application had a greater effect on tree performance than fertilization. Hexazinone increased first-year ground diameter by 17 percent, which equated to a 50-percent increase in volume index. Tip moth infestation was also lower in the hexazinone treatment. Fertilization did not affect first-year growth. The "complete" fertilizer treatment kept tip moth infestation rates at the control level (51 percent) and lower than the diammonium phosphate treatment (66 percent).

INTRODUCTION

As southern pine plantation management intensifies, many forest companies are grouping their land based on soil properties in order to develop more intensive, site-specific, silvicultural prescriptions.

The upper coastal plain of Alabama and Georgia consists of many different kinds of soils ranging from deep, excessively well-drained sands to slowly permeable clayey soils. The deep sands are often the least productive since they have a low moisture-holding capacity and are inherently infertile. However, pine plantations on deep sands can be a strategically important source of wood because they can often be logged during wet weather when other soils are prone to deep rutting. As the timber industry strives to comply with best management practices concerning wet weather logging and the AF&PA Sustainable Forestry Initiative, it becomes increasingly important to maximize productivity on sites that can be logged during wet weather.

As part of an attempt to identify the productive potential of deep sandy soils, a study was established in the Georgia Sandhills region. The objective of this study was to determine if herbaceous weed control (HWC) and/or fertilization could substantially improve the establishment and early growth of loblolly pine on a deep, excessively well-drained sandy soil. This paper reports first-year results.

METHODS

The study is located in Macon County, GA, on a Lakeland soil series (Typic Quartzipsamment). The previous pine plantation was clearcut in 1995, chemically site-prepared with hexazinone, burned, and machine planted in early 1996. In April 1996, the experiment was installed.

The study design is a complete randomized design with a factorial combination of two HWC treatments and three fertilizer treatments, replicated three times. The two HWC treatments were: (1) control, and (2) hexazinone (VelparL applied at a rate of 24 ounces per acre). The three fertilizer treatments were: (1) control, (2) diammonium phosphate (DAP) applied at a rate of 250 pounds per acre, and (3) a "complete" fertilization consisting of ammonium nitrate applied at a rate of 330 pounds per acre and a complete fertilizer (0-7-21 with micronutrients. Micronutrient blend analysis: 7 percent phosphorus 205, 21 percent potassium 20, 8 percent calcium, 2 percent magnesium, 9 percent sulphur, 0.5 percent boron, oxygen, 75 percent copper, 1.3 percent manganese, [0.13 percent water soluble manganese], and 0.75 percent total zinc) at a rate of 350 pounds per acre. Treatments were applied in 3-feet bands around each planting row.

Measurement plots were 0.1 acres (66 by 66 feet) within a 0.25 acre treatment area (105 by 105 feet). After the first growing season, seedling survival, height, ground diameter, and tip moth infestation were measured. Tip moth infestation was calculated as the percentage of buds in the terminal and top lateral branches that were infested by tip moth.

Foliage was sampled from 10 dominant trees in each plot (from 2 nonadjacent trees in each of 5 rows). Five fascicles of needles were removed from each of these 10 trees. Foliage was oven dried at 71 °C, weighed, ground, and sent to Waters Agricultural Lab (along with some standard tissue of known concentration) for nutrient analysis.

To assess HWC and fertilizer treatment effects and interactions, data were analyzed by analysis of variance. An arcsine transformation was made to the survival data for assessment of treatment effects, but not to the tip moth data because its distribution appeared to be relatively normal. A volume index was determined for each seedling by multiplying ground diameter squared times height. For

[1] Research Supervisor, Mead Coated Board, 1000 Broad Street, Phenix City, AL 36867-5920; and Forester, Champion International Corporation, Hwy 269 South, P.O. Box 3608, Jasper, AL 35502 (respectively).

all foliar nutrient concentration data, a Duncan's multiple range test was performed (alpha = 0.1) to identify treatment effects.

RESULTS AND DISCUSSION

The Lakeland soil used in this study is typical of much of the Sandhills. The soil is a deep, coarse, excessively well-drained sand with no argillic horizon within 80 inches of the surface. This soil type is not routinely chosen as a candidate for early HWC because the competing vegetation does not seem very vigorous. After the first growing season, this site had approximately 40 percent ground cover and species such as yucca (*Yucca spp.*) and prickly-pear (*Opuntia spp.*) were common.

The effects of hexazinone and fertilizer treatments on tree growth parameters are presented in table 1. For all parameters, the probabilities of falsely concluding that different means are attributable to treatment effects are presented as P>F. For purposes of discussion, a treatment effect will be considered "significant" if the P>F value was less than 0.1. There were no significant interactions of HWC and fertilizer treatments for any of the tree growth parameters measured in this study.

Overall, survival was about 89 percent, and not significantly affected by hexazinone or fertilization (table 1).

With respect to tree growth, the strongest treatment effect was the influence of hexazinone on seedling diameter. Ground diameter was significantly greater in the herbicide treatment (0.49 versus 0.42 inches) (table 1). This corresponded with a 51 percent increase in volume index. Fascicle weight was also higher in the hexazinone treatment (5.7 grams versus 4.9 grams). Assuming that higher fascicle weight is indicative of a greater leaf area, it seems likely that the trees in the hexazinone treatment will continue to grow at a faster pace in future years.

The hexazinone treatment also had higher foliar nitrogen (N) concentrations (1.6 versus 1.49 percent) (table 2). It seems unlikely, however, that the increased foliar N concentration observed in this study is the cause of greater growth in the hexazinone treatment, since even the control levels are much higher than the considered threshold levels for N sufficiency of 1.1 percent to 1.2 percent.

None of the fertilizer treatments had a significant effect on tree growth, fascicle weight, or foliar N or phosphorus (P) concentration. Considering that the N and P concentrations of the control treatment were greater than the deficiency levels of 1.2 percent and 0.1 percent respectively, it is not surprising that the fertilizer treatments did not increase tree growth. It is surprising, however, that the high rate of N applied in the "complete" treatment (100 lbs N per acre) did not produce a significant increase in N concentration, whereas the application of hexazinone without any added N did increase foliar N. The "complete" treatment did result in significantly higher concentrations of potassium, boron, and manganese (table 2).

As pine plantation management intensifies, concern about tip moth is also increasing. When foresters spend money to accelerate early growth of pine with treatments such as HWC and fertilization, tip moth damage can become a significant problem if infestation is high enough to prevent the benefits of these applications from being realized.

Tip moth infestation was significantly influenced by both HWC and fertilization (table 1). In this study, there were fewer infested buds following the last generation of tip moth (measured in October) in the hexazinone treatment than in the control treatment (50 percent versus 61 percent). With respect to fertilizer treatments, tip moth incidence was higher in the diammonium phosphate (DAP) treatment than in the control and "complete" treatment.

Table 1—First-year growth by treatment of loblolly pine on a Lakeland soil series in Macon County, GA

Treatment	Survival	Height	Ground diameter	Volume	Fascicle weight	Tip moth infestation
	Percent	---------*Inches*	*---------*	*Inches^3*	*Grams*	*Percent*
Herbicide:						
Control	90.4	15.5	0.42a	3.3a	4.9a	61a
Herbicide	87.3	16.7	0.49b	5.0b	5.7b	50b
P>F	0.45	0.29	0.02	0.06	0.03	0.04
Fertilizer:						
Control	93.0	15.3	0.43	3.5	5.3	51a
DAP	87.2	16.6	0.48	4.7	5.4	66b
Complete	86.5	16.5	0.45	4.2	5.2	50a
P>F	0.37	0.58	0.38	0.49	0.86	0.02

DAP = diammonium phosphate.

Table 2—Foliar nutrient analyses by treatment of loblolly pine on a Lakeland soil series in Macon County, GA (values followed with different letters are significantly different at P<0.1 according to Duncan's multiple range test)

Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Boron	Manganese
	Percent				*Parts per million*		
Herbicide							
Control	1.49a	0.18	0.48	0.28	0.07	25	981
Herbicide	1.60b	0.17	0.45	0.30	0.07	29	935
Fertilizer							
Control	1.51	0.17	0.44a	0.28	0.07	18a	807a
DAP	1.53	0.18	0.44a	0.29	0.07	18a	987ab
complete	1.58	0.17	0.53b	0.30	0.07	45b	1087b

DAP = diammonium phosphate.

It is difficult to explain the reasons for these treatment effects on tip moth or speculate about their meaningfulness. It was interesting to note, however, that the "complete" treatment had a significantly lower infestation rate than the DAP treatment. One of the reasons for including this "complete" treatment was to test the hypothesis that micronutrients might play a role in reducing tip moth infestation. These early results warrant further attention to tip moth effects as this study progresses.

CONCLUSIONS

This study was established on a deep, excessively well-drained upper coastal plain site to evaluate the effect of HWC and fertilization on first-year tree growth. Hexazinone application was associated with a greater seedling diameter growth, a greater needle fascicle weight, higher foliar N concentration, and lower tip moth infestation. There were no beneficial treatment effects attributable to fertilization; however, it was observed that fertilization with micronutrients resulted in lower tip moth infestation than fertilization without micronutrients.

The study site used for this experiment had about 40 percent groundcover after the first year, and would not operationally receive an HWC treatment. However, if these first-year growth effects continue in the future, this study may provide justification to begin treating these sites with hexazinone in the first year even though groundcover is not as dense as other soils.

ACKNOWLEDGMENT

The authors would like to thank Cheryl Stewart, Dana McReynolds, and Kelvin Welch for their assistance in this study.

PILOT STUDY SUGGESTS AN ECONOMIC RETURN TO FERTILIZING LATE-ROTATION LOBLOLLY PINE ON A PIEDMONT SOIL

David L. Gartner and William H. McKee, Jr.[1]

Abstract—Economic rates of return for fertilizing early and midrotation loblolly pine (*Pinus taeda* L.) can exceed 15 percent on selected stands. Can similar rates of return on fertilization be achieved on late rotation stands? To determine the answer, 35-year-old, pole-sized planted loblolly pine stands on an eroded Piedmont site were fertilized with 120 pounds of nitrogen and 68 pounds of phosphorus per acre. Five 1/10-acre plots were placed in the treatment area and an associated control area. Foliar nutrient analysis suggests that the fertilizer effects lasted only 4 or 5 years. Because of different initial stand levels of basal area and volume, the data were analyzed using an analysis of covariance. The analysis of covariance showed a $92 per-acre increase in value due to the fertilizer treatment. Due to the large amount of variation, this $92 per-acre increase was not statistically significant. However, the short time between fertilization and harvest caused this $92 increase to create a 12 to 15 percent rate of return on investment. Because the $92 increase is small relative to the estimated standard deviation ($96), future research will need to use larger numbers of plots to get statistically significant results.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) has come under increasingly intensive management, typically including fertilization at establishment and midrotation (11 to 15 years) (Allen 1987, Bengtson 1979). Common rates of fertilization are 100 to 200 pounds of nitrogen and 25 to 50 pounds of phosphorus per acre. Most fertilization research has concentrated on either newly established stands or stands near midrotation. Very little research has been done on the effects of fertilization of late-rotation loblolly pine stands.

Gent and others (1986) studied the effect of fertilizing loblolly pine stands on poorly drained lower coastal plain soils and found that the nitrogen and phosphorus fertilizer used at establishment was still having a growth effect up to 12 years after fertilization. Fisher and Garbett (1980) and Stearns-Smith and others (1992) found that the volume growth response to fertilization continued up to 8 years after treatment for loblolly and slash pine (*Pinus elliottii* var. *elliotti* Englem.) at midrotation. Duzan and others (1982) and Wells and others (1976) created prediction equations for the effects of fertilization on midrotation slash pine and loblolly pine stands. Because stand growth slows with stand age, the ability of a stand to respond to fertilization also decreases with stand age. This operational scale pilot study was designed to determine if economic results from fertilization found for early and midrotation stands can be achieved with older, pole-sized stands.

MATERIALS AND METHODS

Location and Site Conditions

The study site is located on the Sumter National Forest in Union County, SC. The soils are in the Cecil and Pacolet soil series (Camp and others 1975). The site has a long agricultural history followed by reforestation. The soils within the study area sites have the B horizon at or near the surface, suggesting that the surface erosion had been severe. There is little organic matter in the surface soil horizon. Soil samples from the top 4 inches were consistently acid (pH 4.6 to 5.3), low in soil nitrogen, at least by agronomic standards (281 to 492 parts per million), and low in available phosphorus (1.0 to 14.4 ppm) (Bray P2) (Jackson 1958).

Stand Conditions

Trees were hand-planted with 1-0 seedlings around 1951 on a 6- by 10-foot spacing. Approximately 200 to 250 trees per acre remained at the time the study was installed. Reductions in stocking since time of establishment have resulted from either thinning or mortality. Records of exact planting dates and thinning intensities are not available. Understory vegetation was sparse in all stands and consisted mainly of broomsedge (*Andropogon* sp.) and brambles (*Rubus* sp.).

Experimental Design

The study area was split into six strips. Three strips were not fertilized. The other three strips were fertilized with a combination of diammonium phosphate and urea as a 35-16-0 (nitrogen:phosphorus:potassium) ratio at 400 pounds per acre. The fertilizer was applied on an operation basis, using a helicopter, on April 22, 1986. Five square 1/10-acre measurement plots were located randomly within the three strips for each treatment for a total of 10 plots. Corners of plots were monumented with treated wooden stakes. Trees within plots were identified with numbered metal tags attached to trees with aluminum nails at breast height.

Measurements

Soil samples were collected from the surface 4 inches of the plots. Ten to 15 cores were taken at random from each plot and composited. Samples were air-dried and analyzed for pH, total nitrogen (Nelson and Sommers 1973), and available phosphorus (Bray P2) (Jackson 1958).

[1] Mathematical Statistician and Research Soil Scientist (retired), respectively, USDA Forest Service, Southern Research Station, Center for Forested Wetland Research, 2730 Savannah Highway, Charleston, SC 29414.

Foliage nutrient levels were measured during the dormant season before the fertilizer application and annually for 3 years following fertilization. Foliage samples were collected from the upper third of the crown on the south side of the tree with a shotgun. Material from the first flush of the previous growing season was saved for analysis. Needles were oven-dried for 24 hours at 70 °C and ground to pass a 40-mesh screen. Nitrogen concentrations in the needles were determined by the salicylate-cyanurate method (Nelson and Sommers 1973). Concentrations of phosphorus in the needles were determined by dry ashing a 1.0 gram sample at 450 °C, taking up in 0.3 M HNO_3, and analyzing for phosphorus by the molybdovanadate method (Jackson 1958).

Stem diameters at breast height (d.b.h) were measured before fertilization and annually for 4 years following fertilization to the nearest 0.1 inch with a diameter tape. Heights were measured to the nearest 0.1 foot with a visual caliper in 1987 and 1989.

Computed Variables

Basal areas and stem volumes were calculated from the height and diameter measurements. Per-acre basal area was derived as the sum of stem basal areas per plot and expanded to a per-acre basis by multiplying by a factor of 10. Total volume (cubic feet), inside bark, was calculated using equation 1.

$$TV = 0.00148209 \times dhb^{1.9229} \times height^{1.1105}, \quad (1)$$

where
TV stands for total volume inside bark.

Merchantable volumes (cubic feet) to a 4 inch top were computed using equation 2 from Clutter and others (1984).

$$MV = TV \times (1.0 - 0.5694 \times 4.0^{3.4304} \times dbh^{-3.2395}), \quad (2)$$

where
MV stands for merchantable volume inside bark.

The results of these calculations and their values per acre were summed by 1-inch diameter classes.

Dollar values for the diameter classes were developed from the Timber Mart South's first quarter 1989 standing timber prices for South Carolina Piedmont and the percentage of stems in various diameter classes found in Broderick and others (1982). The Timber Mart South's prices were: pulpwood at $17.24 per cord, sawtimber at $193 per thousand board feet (mbf) (Scribner), and peelers at $191 per mbf (Scribner). These prices were converted to cubic feet by assuming 2.8 cords per mbf and 5.5 mbf per thousand cubic feet (mcf). The merchantable volume in each diameter class was allocated to the different products according to the percentages given on table 4 of Broderick and others (1982). Volume between the 4-inch top and the minimum end diameters for sawtimber and peelers (6-inch and 8-inch, respectively) were discarded. Because sawtimber went for a higher price than peelers, stems that could be sold as peelers were assumed to be sold as sawtimber. An average price for each diameter class was created by weighting the price of each product class by the percentages of the stems sold as that product, and summing these weighted prices together.

Data Analysis

The experimental unit was the treatment strip. For each treatment, two of the strips had two measurement plots. The data from these two plots were averaged together to create a strip-level mean.

The strips from the two treatment groups had different initial values for basal area per acre, volume per acre, and dollar value per acre. Woollons's (Woollons 1985, Woollons and Whyte 1988) recommendation of using analysis of covariance for adjusting for initial basal area in fertilizer studies was followed. The dependent variable in the analysis of covariance is the change in dollar value per acre. All significance tests used a $p = 0.05$ level of significance.

RESULTS

Foliage Nutrients

The average pretreatment leaf nitrogen levels were 1.27 percent for both the fertilized and nonfertilized plots (table 1). There was no effect of fertilizer on the leaf nitrogen concentrations. The leaf phosphorus levels followed a pattern that was consistent with the fertilizer giving a short pulse of phosphorus that diminished with time. The pretreatment phosphorus levels were .122 percent for the nonfertilized plots and .109 percent for the fertilized plots. The first year after treatment, the fertilized plots increased in phosphorus concentration relative to the nonfertilized plots. During the second year, this increase had diminished. By the end of the third year, the fertilized plots had returned to a lower leaf phosphorus concentration than the nonfertilized plots. These responses indicate that the

Table 1—Effect of fertilization on foliage nitrogen and phosphorus levels for 3 growing seasons following treatment

Year and treatment	Nutrients Nitrogen	Phosphorus
	-------------*Percent* -------------	
1986 (before fertilization):		
No fertilizer	1.27	.122
Fertilizer	1.27	.109
1987 (1st year):		
No fertilizer	1.20	.114
Fertilizer	1.21	.125
1988 (2nd year):		
No fertilizer	1.09	.107
Fertilizer	1.06	.113

fertilizer effect on the foliar nutrient concentrations of pole-sized trees is short lived, probably 4 or 5 years.

Stand Growth

The unfertilized stands grew more in height (10.9 feet versus 8.2 feet), basal area per acre (10.0 square feet versus 9.4 square feet), volume per acre (959 cubic feet versus 765 cubic feet), and lost fewer trees per acre (8 versus 18) than the fertilized stands. At first glance, these results suggest that the fertilizer treatments did not increase the yields of these stands. However, the fertilized plots started with taller trees (62.2 feet versus 56.1 feet), more trees per acre (256 versus 230), larger quadratic mean diameter (9.21 inches versus 9.08 inches), more basal area per acre (118.5 square feet versus 103.5 square feet), and more volume per acre (3578.4 cubic feet versus 2867.2 cubic feet) than the unfertilized stands. The fact that the fertilized stands started with larger trees and larger basal areas suggests that these stands were further along in their development and closer to their maximum carrying capacity than the control stands. These differences in initial stand conditions led to the analysis of covariance.

Analysis of Covariance

An analysis of covariance was used to account for these differences in initial basal area, using the change in dollar value as the dependent variable with the initial basal area as the covariate. The analysis was run on the strip averages under the assumption that the measurement plots were subsamples. The standard statistical assumptions for analysis of covariance were used. The adjusted mean increase for the control plots was \$596 per acre. The adjusted mean increase for the fertilized plots was \$688 per acre. This gives a difference of \$92 per acre due to fertilization. The estimated standard deviation was \$96 per acre. Because of the large variation between stands and the small number of strips, this \$92 per acre difference was not statistically significant ($p = 0.43$).

DISCUSSION

Even though this \$92 per acre increase in value is not statistically significant, the short time span between the investment and the realization of the investment caused the investment to have a high rate of return. The fertilizer cost was \$52 per acre.[2] The \$92 per-acre increase in value caused by fertilization leaves a \$40 net profit. Using simple annual compounding, this leads to a 15-percent rate of return if the profit is realized in 4 years, and a 12-percent rate of return if the profit is realized in 5 years. These are fairly high rates of return for the landowner.

The main problem with the rates of return is that the \$92 per acre increase is not statistically significant. Statistical significance is a function of three quantities: the size of the effect, the amount of variation, and the number of plots. The number of plots required to obtain a statistically significant result was calculated using the size of the effect (\$92 per acre) and the amount of variation (\$96 per acre) from this study. To have a 50-percent chance of a statistically significant result, an experiment would have to have at least eight plots: four control plots and four fertilizer plots. To have a 75-percent chance of a statistically significant result would require 16 plots, and to have a 90-percent chance of a statistically significant result would require 24 plots.

SUMMARY

1. The results from this study suggest that late-rotation fertilization of loblolly pine will cause a small increase in dollar value gain (\$92 per acre).
2. Because of the short turnaround time between fertilization and harvesting, small dollar increases can cause high rates of return on investment. The rates of return from this study range between 12 percent and 15 percent. The short turnaround time also causes the rate of return to be greatly affected by price fluctuations.
3. Because the suggested gain is smaller than would be observed with early or midrotation fertilization, large study sizes will be needed to obtain a statistically significant result.
4. Stearns-Smith and others (1992) found that price differences between pulpwood and sawtimber were required to make midrotation fertilization of loblolly pine profitable. Our results agree with their analysis. If only pulp prices are used in this study, the \$92 per-acre increase due to fertilization drops to a \$7 per-acre loss.
5. Results of fertilizing late-rotation loblolly pine will be affected by differences in site and differences in amounts of fertilization. Further research will be required to determine where fertilization is economically feasible.
6. When the study was started, Bill McKee was part of a soil productivity unit. Bill McKee's part of the soil productivity unit was merged into a forested wetlands research unit. Therefore, the authors are no longer studying loblolly pine fertilization, and would like to encourage those who are researching the effects of fertilization on loblolly pine to consider studying late-rotation fertilization.

ACKNOWLEDGMENT

This study was undertaken jointly by the USDA Forest Service, Sumter National Forest and Southern Research Station. The authors would like to thank Dennis Law of the National Forests of South Carolina for his assistance and support for this study. The authors would also like to thank David Wear of the Southern Research Station for his help with the economics in this paper.

LITERATURE CITED

Allen, H. Lee. 1987. Forest Fertilizers. Journal of Forestry. 85: 37-46.

Bengtson, George W. 1979. Progress and needs in forest fertilization research in the South. In: Forest fertilization – theory and practice. Knoxville, TN: Tennessee Valley Authority: 234-244.

[2] Personal communication. 1995. Dennis Law, Soil Scientist, Francis Marion and Sumter National Forests, 4931 Broad River Road, Columbia SC 29210.

Broderick, Stephen H.; Thurmes, John F.; Klemperer, W. David. 1982. Economic evaluation of old-field loblolly pine plantation management alternatives. Southern Journal of Applied Forestry. 6: 9-15.

Camp, Wallace J.; Meetzle, J.C.; Fleming, W.H.; Andrew, L.E. 1975. Soil survey of Laurens and Union counties, South Carolina. Washington, DC: U.S. Department of Agriculture, SCS. 165 p.

Clutter, J.L.; Harms, W.R.; Brister, G.H.; Rheney, J.W. 1984. Stand structure and yields of site prepared loblolly pine plantations in the lower coastal plain of the Carolinas, Georgia, and North Florida. Gen. Tech. Rep. SE-27. U.S. Department of Agriculture, Forest Service. 173 p.

Duzan, Howard W., Jr.; Allen, H. Lee; Ballard, R. 1982. Predicting fertilizer response in established loblolly pine plantations with basal area and site index. Southern Journal of Applied Forestry. 6: 15-19.

Fisher, R.F.; Garbett, W.S. 1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. Soil Science Society of America Journal. 44: 850-854.

Gent, J.A.; Allen, H.L.; Cambell, R.G.; Wells, C.G. 1986. Magnitude, duration and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. Southern Journal of Applied Forestry. 10: 124-128.

Jackson, M.L. 1958. Soil chemical analysis. Englewood Cliffs, NJ: Prentice-Hall, Inc. 298 p.

Nelson, D.W.; Sommers, L.E. 1973. Determination of total nitrogen in plant material. Agron. Journal. 65: 109-112.

Stearns-Smith, Stephen C.; Jokela, Eric J.; Abt, Robert C. 1992. Thinning and fertilizing southern pine stands of the lower coastal plain: biological and economic effects. Southern Journal of Applied Forestry. 16: 186-193.

Wells, Carol G.; Crutchfield, C.M.; Trew, I.F. 1976. Five-year volume increment from nitrogen fertilization in thinned plantations of pole-sized loblolly pine. Forest Science. 22: 85-90.

Woollons, R.C. 1985. Problems associated with analysis of long term *Pinus* fertilization X thinning experiments. Australian Forest Research. 15: 495-507.

Woollons, R.C.; Whyte, A.G.D. 1988. Analysis of forest fertilizer experiments: obtaining better precision and extracting more information. Forest Science. 34: 769-780.